To: April 24th seminar attendees

From: Dan Raff

In re: Attached text

In the seminar this Thursday, I intend to discuss a problem, an intriguing data source, and some preliminary findings. There is more detail on all of this in the attached text. (I hope to bring with me some illuminating photographic images as well as the figures.) I'm a little bit ahead of the text at the moment and I'm certainly not done with probing the data yet, so I will want both to present to you and to pick your brains a little. But the drift should be clear enough from what follows this note.

I should perhaps add, in case it is not obvious, that the text is ultimately aimed at an audience that contains people trained in economics but is not confined to them.

What Happened at Highland Park?

Daniel M.G. Raff

The Wharton School and National Bureau of Economic Research

raff@wharton.upenn.edu

This revision: April 20th, 2003

Lawrence Summers, long ago in joint work on a different project, provided the itch to which this manuscript represents a provisional scratch. The text has benefited from presentations to the Penn Economic History Forum, the Development of the American Economy and Industrial Technology and Productivity groups at NBER, and the annual meetings of the Economic History Association. I learned a great deal form these audiences and had particularly helpful comments and advice from Ned Bowman, Lance Davis, Therese Flaherty, Claudia Goldin, Zvi Griliches, Margaret Levenstein, Tom Sugrue, and Robert Zevin. Charles Christianson and Sam Parker provided expert advice on a subtle accounting matter that proved to be of foundational importance. I also owe thanks to Thomas DeFazio for many valuable conversations on automobile manufacturing matters. Plant visits and on-site interviews arranged by Volkswagen A.G. and Automobili Lamborghini were also very illuminating. I thank the National Science Foundation, the University of Pennsylvania Research Foundation, and the NBER Industrial Technology and Productivity Program, the latter funded by a grant from the Sloan Foundation, for financial support. Suggestions and comments remain welcome. The usual disclaimer applies.

WHAT HAPPENED AT HIGHLAND PARK?

1. Introduction

For much of the first decade of this century, the Ford Motor Company was in most outward respects indistinguishable from the other firms then entering the industry in vast profusion. One of its owners was a mechanic by training who had built a prototype out of purchased and made-to-order parts. The other owners were predominantly well-to-do acquaintances of his who invested relatively small sums and knew little about the technology or the details of the business. Parts for the vehicles were initially almost entirely bought in. They were assembled using artisanal methods in short production runs and with low throughput rates. The parts were purchased on 90-day credit; and the finished cars were sold before these bills fell due. If one could make a few cars, one could make a little money. Many companies did both.

The most striking fact about Ford in this context was summarized by the author of the first scholarly study of the company in Table 1 below. Ford was the first company in the industry to make the transition to large-scale production. The company generated profits in the course of doing this that were not merely incremental but unambiguously tremendous, making the least of its original owners very well off and the greatest of them, it is said, briefly the wealthiest man on the planet. In doing all this, the company had to solve a series of inter-related problems in product design, logistics, operations management, personnel management, and marketing.[1] The operations management ones were the most conspicuous ones. However profoundly or superficially the mix was understood, however, the industry and the world understood that there was a problem of mass production and that Ford had solved it.

--Table 1 about here--

The solution is of broad interest for a number of reasons. The industry, which was not large enough to merit a separate category in the manufacturing census covering 1899, had grown big and otherwise prominent enough to have been covered in the succeeding two by 1909, when the exciting events at Ford were beginning to get under way. By 1929, it was the largest in the Census by several obvious measures. Industrial development of such dramatic proportions seems a sort of philosopher's stone of economic growth. Furthermore, the growth, however late it came in America's development as an industrial nation, had profound effects on the development of supplier industries and competences and on the character of work for a very large labor force. The output of the industry also had far-reaching effects on how people lived their lives and where work and home came to be located. This is an industry of general interest.

---

[1] On the facts, see, e.g., Raff 1987, Meyer 1981, and Tedlow 1990. See also Section 2 below. On why the inter-relatedness might be important, see Milgrom and Roberts 1990.

It is also of interest because of the substance of what happened. The history of the growth of this industry is at one level the history of a transition from an essentially artisanal production technology to a large scale and modern one that was replicated, with appropriate variation, in many industries and even service sectors.[2] The coming of mass production to Ford is an archetype as well as an avatar of an age: in many parts of the world, mass production is identified with the American Century.

When we seek an icon of mass production now, the visual image that comes first to mind is the famous aerial photograph of the Ford River Rouge plant, with its boats unloading iron ore from the Mesabi Range and rubber from the tropics and its railroad cars carrying out finished cars. But the Rouge did not operate in its full capacities until the 1920s; and in the period in which the main problem was solved, the Rouge was not yet even a gleam in the eye of its creator.[3] In the days with which this paper is concerned, when the journalists wrote of the immense quantities of all sorts of inputs and the output, one day=s worth of which, Aleaving the factory half a mile apart, would reach from Detroit to New York City,@ the image called up in the popular eye was of the great predecessor plant at Highland Park.[4] It was this plant that was identified, within the Company as well as in the outside world, with the Model T. It was inside this plant that the moving assembly lines for making automobiles were first and most famously deployed. It was outside the gates of this plant that the mobs queued for jobs after the announcement of the Five Dollar Day. If Ford meant mass production, so did Highland Park.

The objective of this paper is to develop a quantitative microeconomic history of this first true coming of mass production to American automobile manufacturing. That history has by turns been primarily in the hands of technical journalists, biographers, automotive historians and car buffs, commentators on labor history, labor historians proper, and most recently historians of technology.[5] But the curious fact of the matter is that in a time in which the mechanisms of economic growth, the causes and magnitudes of productivity improvement, and the characteristics and patterns of technology transitions are all matters of intense interest to academics and even more practical people, not much liaison has yet been made. I want to make a start.

The start I want to make is not the usual economist one, however. I believe that to understand

[2] The contrast between the organization of production at the fast food franchisees of MacDonald=s and Burger King is a classic of introductory operations management courses. MacDonald=s is the Ford of its business.

[3] See Appendix Section 0.1.

[4] The quoted phrase is from Colvin 1913, p. 757.

[5] For example, the papers and books in the Bibliography below by Colvin and Arnold and Faurote, Sward and Nevins, Rae and Thomas, Braverman, Meyer, and Hounshell, respectively. Lewchuk=s book does not fit into this categorization so neatly. But see Section 1.5. below.

what happened at Highland Park from this perspective, one must understand the choices that particular actions represented. To understand the choices, one must understand not just their characterizations but their direct consequences. I therefore certainly do want to use the history of technology to illuminate the history of productivity growth. But I also want to use the history of productivity growth to illuminate the history of technology. I hope the conjunction will shed some light on industry dynamics in a more conventionally economic sense.

One reason that the events at Ford have been viewed as they have been is that they were pregnant with significance. But another is undoubtedly that until very recently there was no very fine microeconomic data. The literature contains repeated citations of coarse quantitative data from the Ford Archives (physical output, average total employment, and so forth) and benchmark comparisons of the crudest sort from the Census of Manufactures. But aside from two tables in a subsidiary chapter in Lewchuk's 1987 book drawing on the Model T Cost Books, this is essentially all there is; and even those two tables, while intriguing, do not go far in addressing big questions.[6]

In the 1920s, the minority shareholders bought out by Ford late in the previous decade were sued by the Internal Revenue Service for additional taxes. (The opening section of the Appendix gives more detail on all matters touched upon in this paragraph.) Many artifacts of great interest to the historian of the automobile industry were generated in the course of the suit. Many of these, accessibly filed at the Ford Archives, have been consulted with profit and even quoted by historians. But not all of the materials got to Dearborn. In the furthest recesses of the storage area of the National Automotive History Collection in the Detroit Public Library are a number of boxes and ledgers connected to the Ford Additional Tax Suit. Ford had been obliged in the suit to document quantitatively the financial history of his company. The Detroit Public Library ledgers, which do not replicate materials in the Archives, contain photo-reproductions of something very close to the primary source of balance sheet information. This integrated source give its information at an unusually fine level of disaggregation. More remarkably still, it also consistently covers a great deal of information about factor inputs and

[6] Since writing the original draft of this paper, I have discovered Williams et al. 1993. That paper is oriented toward a different literature than this one but is carried out along closely related lines. Unfortunately, much about its execution is problematic. The sources relied upon are fragmentary, coming from here and there in the Ford Archives, and are not obviously consistent with one another in their definitions. (See the opening section of the Appendix to this paper for the positive case for the data source relied upon here.) The data Williams et al. rely upon exists only at the annual frequency, so they have no way to check whether the periodization behind the annual patterns they show summarizes or distorts what was happening month to month. Perhaps most important, their analysis embodies several markedly peculiar assumptions about the underlying economic structure of the data, not the least of which is the apparent assumption that the marginal product of capital is consistently zero. This is a particularly bizarre idea for computations about this factory and period, as the discussion in Section 2 below may suggest.

operations. And all of this is given at a monthly, rather than an annual, frequency. The calculations I discuss here exploit these data, occasionally complementing them with (or checking them against) information from other sources in the Ford Archives proper.

Altogether, the data I mobilize are sufficient to build up a quantitative picture of the coming of mass production to Ford as an event in the history of productivity growth. One subsequent step in the larger project of which this paper is a part will be to compare that picture to the ones one can create for the small number of other contemporary firms for which (even remotely) comparable data survive. Luckily, the firms in question are not totally obscure, and they offer up interesting contrasts. After developing these, I hope to study the dynamics of transition in the industry.

2. Buildings, Machines, Methods, and Practices More Generally

It is appropriate to begin with some institutional history of assets, activities, and organization. The account in the company history of Nevins referred to above has been shown to be less than entirely reliable. In this section I follow Hounshell=s masterful revision, often very closely.[7] Any claim to novelty here lies not in what is remarked upon in this section but rather in how and with what it is combined in the rest of the paper.

Henry Ford built a prototype vehicle in his garage, but his earliest commercial production was carried out in rented shop space on Mack Avenue in Detroit. This was a space appropriate to general light industry--there was nothing particularly well adapted to Ford=s product or any particularly novel methods. On the other hand, there was nothing unusual about Ford's methods at this stage. The operation was for practical purposes entirely assembly. The parts came in manufactured to low tolerances. Skilled mechanics put the cars together, fitting parts as required using files and hammers when these were appropriate and general purpose machine tools when those were.

Activity moved in 1904 for the first time to facilities Ford built and owned outright. These were on Piquette Avenue at Beaubien in Detroit (and were used by other well-known early automobile manufacturing firms after Ford moved out). These facilities seem to have been designed principally for assembly rather than manufacturing: there was no room for large groups of machines. The space was certainly bigger but not by that all not much; and in many respects it was not better. This was a three-story building roughly 400 feet long and 50 feet wide. It was dark and not particularly flexible in how the space inside could be used. Some manufacturing functions were at this time carried out by a separate manufacturing company owned by Ford and a colleague in rented quarters on Bellevue Avenue. The Piquette Avenue building was expanded in 1907 and the Bellevue operations, legally combined at the same time into the downstream company, were physically moved in as well, thus

---

[7] See in particular Hounshell 1984, chapter 6.

consolidating parts making and assembly. There and thus the company stayed through 1909.

The first real evolutionary event came in this period with the hiring in the springtime of 1906 of Max Wollering and four months later of Walter Flanders. Wollering had had a career as a manufacturing mechanic and, in due course, a superintendent. He worked for Ford as superintendent of the manufacturing plant. Flanders, a Vermont native, had previously worked as a machinist and an unusually knowledgeable salesman of machine tools. One of his customers had been Henry Ford. Ford had hired Wollering on Flanders=s recommendation; and four months after that he hired Flanders as well in the capacity of overall production manager.

Flanders had direct experience from previous work in New England of American System manufacturing methods.[8] Wollering maintained in his Reminiscences that this was all familiar to him as well.[9] It was in any case not at the time the practice of the company, and the two of them worked hard at introducing the methods. Though both left in 1908, Hounshell thinks of the period of 1906 through at least 1910 as a period in which the main meta-activity in the plant was the absorption, adaption, development, and exploitation of American System methods. In particular, these years saw the beginnings of careful attention to the true interchangeability of parts (and the gauging systems required to support this), the development and use of single-purpose machine tools, and the placement of machine tools in sequences dictated by the sequence of production tasks rather than by the categories of machines (i.e. all lathes in one place, all milling machines in another, and so forth.) How far these first two of these efforts had gotten by any particular date is not yet clear, though enough of the third--by far the most easily accomplished--was in place prior to 1907 for a visiting technical journalist to notice it.[10] Whatever the progress was, it is clear that it would only have been supported by the introduction of the unluxurious Model T in October, 1908, and, more pointedly still, by the 1909 decision of Ford himself, by then the majority shareholder in the company, to produce no models other than Model T=s and to produce all Model T body models on a single chassis.[11]

---

[8] On the American System, see Smith 1977, Rosenberg, ed., 1969, Rosenberg 1963, Mayr and Post, eds, 1982, and Hounshell op. cit.

[9] Wollering, Reminiscences.

[10] Colvin actually saw the beginnings of the sequential organization during a plant visit he dates as 1906. See Colvin n.d. (He published nothing of this character about Ford until 1913 due to Ford=s reticence.) On how much harder the other two tasks were, consider how public, plaintive, and clearly if implicitly focused on interchangeability were Ford=s efforts in the immediate aftermath of the Five-Dollar Day and the publicity about the production systems to engage new suppliers.

[11] The parts of the automobile most resistant to American System methods were the ones luxury buyers cared most about and utilitarian purchasers least. On the Ford policy, see Nevins op. cit., p. 452. On the distinction between body models and mechanical models and the dynamics of the balance in the population of gasoline-powered automobile manufacturers in the even-numbered years 1906-

The old facility was replaced by a new one in the Detroit suburb of Highland Park on January 1, 1910. This was designed by the architect Albert Kahn. Its proportions were generous by comparison to the earlier buildings, but that was the least of what was striking about the design. It was also immensely better lighted: Hounshell estimates that 75 percent of the wall space was glass, and some buildings on the site were well-skylit as well. Most to the point, the light fell on long, open spaces with clear sight-lines. It was a building well suited to large and steady flows of production and easy monitoring of the flow. The demand was there, and the flow did follow.

What innovations took place in the early years of Highland Park? When it opened, the then head of production wrote in his memoirs, it was a Aprogressive@ but not a Afully integrated operation.@[12] We can assume from the very public and poignantly plaintive solicitation by Henry Ford of new parts suppliers in the aftermath of the Five Dollar Day that progress on obtaining truly interchangeable parts was slow and difficult.[13] There is documentation in the Ford Archive=s oral histories and in the series of trade illustrated trade journal articles by Abell (in The Iron Age starting in 1912) and Colvin (in The American Machinist starting in 1913) of tremendous innovation in the design of manufacturing equipment. These were innovations that embodied skill in machines--in major part through clever design of jigs and fixtures--or that simply used machines and power to replicate human actions faster than humans could--as in the famous machine that pushed ninety-five radiator tubes at once through the holes in the strips of metal that held them.

It is clear that the design philosophy behind of the first of these three types of innovations was in place by 1913, when Colvin was at last permitted to publish, but it is not at all clear how much earlier the design philosophy began being effected. It is difficult to make any generalizations about the timing or impact of the second--the machine tools to implement the philosophy--other than to take note of the piecemeal aspect of this sort of innovation and the many anecdotes about Henry Ford encouraging employees to observe and improve in all periods. It is also true that in this particular period the company purchased the John R. Keim Stamping Company of Buffalo, importing specialized equipment and staff alike, and replacing in its own operations the traditional casting of many metal automobile parts

---

1940, see Raff and Trajtenberg 1997. (The Raff and Trajtenberg manuscript in progress derives from an annual database that pushes the starting date of coverage back to 1901--the beginning of real commercial activity in the industry in America--and includes manufacturers of steam- and electric-powered vehicles as well. Its statistics will in due course supersede those in the 1997 paper.)

[12] Sorenson 1956, p. 125.

[13] There is some reason to think it only became technically easy in the period of the Highland Park plant itself. See American Society of Mechanical Engineers Subcommittee on Machine Shop Practice 1912. For some distinct but related economic forces, see Helper 1991.

with cheaper but no less effective stamping methods.[14] Yet in contemplating innovations of this second kind two important caveats should be born in mind. First of all, there is an issue of sample selection: one needs to take seriously the possibility that the instances cited in wonderment by contemporary technical journalists and passed down as examples through the secondary literature may indeed have been unusual--rather than, say, modal--in their impact or in the extent to which they represented departures from standard practice. Secondly, one should also take seriously the possibility that being photographed and written up in periodicals for working professionals may have meant that individual innovations diffused swiftly: gadgets may be easy to copy, wave or no, especially if their details are publicized.[15] This would be particularly true in the case of unpatented design innovations in machines manufactured for Ford by vendors who also made up machines for other auto manufacturers. It is unclear a priori how much of this activity benefited Ford alone.

Another aspect of innovation at Ford in this period concerned organization. How were the cars actually put together? There were three phases to the physical organization of assembly. The first was the traditional method of the artisanal shops of static assembly (generally on sawhorses in the middle of a room) by assemblers were themselves static in position except when they had to go get parts or use equipment installed around the perimeter of the room. In the second phase, which began sometime in the Piquette Avenue facility, the workpieces stayed static but the assemblers started moving: the assemblers formed into gangs who moved, roughly speaking, from one set of sawhorses to the next. At the same time, crews of workers proceeded through the same aisles bringing parts: timing and coordination were important. This phase was still in place in many parts of the factory in the second half of 1913.[16] But it was fast being supplanted by the final phase of bringing the work to the men: in Hounshell=s striking phrase, Aevery*thing* put into motion and every *man* brought to a halt.@[17] This final phase begins in the early months of 1913. By November, the entire engine assembly ran on an integrated line. The first experiments with a chassis assembly line--the key to final assembly and thus the development that must really have finally persuaded the managers that the whole factory could be run like a giant Swiss watch--had come in August. By Christmas the thing was not yet perfected but clearly going to work. The Five-Dollar Day followed days later. There were three lines for final assembly by springtime.

---

[14] Amongst the human assets acquired was an employment relationship with W.S. Knudsen, the author of the report of the Assembly Department relied upon in Appendix Section A2.2 below, who in due course became head of production at Ford and in the fullness of time president of Ford=s eventual arch-competitor General Motors.

[15] On the wave of gadgets, see Ashton 1948.

[16] See Colvin 1913d.

[17] Hounshell op. cit., p. 244.

The meaning of the assembly line in this context is only indirectly the control of task pace that is focused on in labor history accounts of these events. In this context, it stands in principly for fixing the worker in space and fragmenting the tasks assigned to him. Controlling flow through the system then required, through the logic of complementarity, controlling flow of work to the worker. Hounshell concludes on photographic evidence--what appears when and what does not--that gravity slides and the most of the mechanized form of piece conveyance appeared roughly contemporaneous to this radicalization of the division of labor.

Broader complementarities amongst the innovations at Ford described above were common and powerful. It is worth explicitly emphasizing, however, that sets of innovations possessing the complementarity property are nonetheless not necessarily implemented all at once. The notion that they are seems widespread amongst economists. It may derive from an exposition of the idea of complementarity in a comparative static setting. It may even be rooted in the notion of a production function as a book of blueprints, each one only ever implemented, in equilibrium, complete and whole. Whichever, it does seem to be rooted in a set of ideas remote from the practicalities of wreaking great change in a many-staged process of manufacturing and assembling a product with well in excess of 10,000 parts. Many of the innovative ideas at Ford were the products of experience. Sometimes this experience was experience of the performance of previous innovative ideas. Even ideas with broad domains of application could not necessarily be implemented at once due to constraints on equipment supply or managerial attention. One attractive feature of high-frequency data in research such as this is that they don=t of necessity--by construction, as it were--disguise such facts.

Some summing up may now be in order. An historical account such as the preceding is revisionist in the following senses. First of all, it places the innovation of moving assembly lines very late in the period of interest. Secondly, contradicting a lovely but apparently inappropriate metaphor of Nevins, it sees gravity slides and the like for parts as coming roughly contemporaneous with, and as part of the logic of, the lines rather than preceding, and inducing, them. Thirdly, it places the great burst of machine invention in the early Highland Park years. Fourthly, it places great emphasis on the advent, extremely early in the story, of (at least the ideas of) American System methods. Finally, it very clearly portrays mass production not as a single innovation but as a congeries of highly complementary practices. It says little crisp on how much any particular mattered, or on what the impact of the whole was; but on all five of the enumerated points it is very crisp indeed.

Two pieces of more conventional historical context should also be born in mind in what follows. The first is that there was a recession starting in 1914 and continuing well into the following year that was exceptionally severe.[18] Secondly, the local economy of Detroit began heating up with the coming of war to Europe. Eventually the whole economy did, and considerable inflation resulted.

[18] It was severe enough to be the prompt to the Federal government to begin keeping employment statistics.

<u>3. Some Very Basic Facts about Growth at Ford</u>

We can now move to data. Some basic facts about Ford=s experience may be of interest. They also lay a foundation for the main work to come.

The traditional historiography was not wrong in its characterizations of output growth it was demonstrably explosive. The monthly numbers plotted in Figure 1 come from the Ledgers (as will all numbers from here on in unless otherwise noted) and they tell the bulk of that story. It is not the only story of any interest. One could, for example, plot sales against price. (See Figure 2 or Table 2.) While the simplicity of that picture encourages the viewer to forget important elements of path dependency in demand in the background (and even the distinction between nominal and real prices), this "demand curve" does slope more or less nicely downwards. Ford did discover the mass market. But the production story is the focus of our interest at present.

--Figures 1 and 2 and Table 2 to go about here--

This production story is undoubtedly superficial presented on its own. So long as unit revenue was in excess of unit total cost, a record such as that portrayed in Figure 1 should have represented a commercial Golconda. And the beginnings of a true Golconda it surely was. (See Figure 3.) But what the production record represents in microeconomic terms is very much less clear. One has but to put the question: What was happening to the inputs?

--Figure 3 about here--

For this output growth did not come entirely out of the air, even the air of innovation. One can see this even in the sort of terms in which the earlier literature is laid out. The labor input was also growing extremely briskly. (See Figure 4.) Output per head was generally increasing on trend, more or less however measured. (See Figures 5, 6, and 7.) But through the end of 1913, what is most striking about these latter plots is not the upward trend, which appears modest, so much as the seasonality. Altogether, these data suggest tremendous expansion before they suggest intensive rewriting of the effort bargain. There are many intervening variables.

--Figures 4, 5, 6, and 7 about here--

A simple intervening variable is other inputs. Growth of the capital input--in the usual sense of the stock of available capital--was itself also very fast. (See Figure 8.) Output per dollar of capital also shows some apparent seasonality, though the upwards trend is more pronounced. (See Figure 9.) An hours-based adjustment for capacity utilization (discussed in Appendix Section A3.2.2.5 below and which, while crude, ought to be better than no adjustment at all) makes this slightly more extreme. (See Figure 10.)

--Figures 8, 9, and 10 about here--

The conventional image of the transition from artisanal production to mass production is one of massive investment in capital and a massive increase in the flow of capital services relative to those from labor. These series begin after the unambiguously artisanal stage of the company=s life, but they do begin very early on in the transition. The conventional image is not the picture shown thusfar, nor is it visible in the capital-labor ratio, either raw or appropriately adjusted. (See Figures 11 and 12.) Expansion of inputs was going on, and on a very substantial scale at that. But something more complicated was happening.

--Figures 11 and 12 about here--

It seems clear then that tracking what was happening requires more sophisticated measurement. It would be interesting to know the magnitude of productivity change to fill out the history of Section 2 and to add some sense of timing to it. It would also be interesting for a reason more internal to the discourse of economists. If the improvements were very big, this as much as the wealth accruing to the owners raises questions of the course of the diffusion of the ideas behind the improvements. The thoughtful reader of my footnotes will correctly infer that owners and engineers in the industry (and indeed in the supply and capital goods industries as well) will have had a reasonably idea of what was going on at Ford. Yet diffusion of the innovations on any but the most superficial levels seems to have been very slow. If the productivity growth, appropriately measured, was actually very large, the reasons diffusion took the course it did deserve very careful attention.

4. Measuring Productivity (Relatively) Carefully

Thus productivity needs to be measured in at least a moderately sophisticated way. Total factor productivity growth is the obvious approach to try.

Solow 1957 is generally taken to be the starting point of modern productivity measurement.[19] The basic empirical observation behind the paper is that productivity measurement ought to take into consideration the positive value of all measurable inputs and ought to focus attention on the growth in output that cannot be explained simply as a consequence of the growth of these inputs. Solow, a macroeconomist interested at the time in the process of aggregate economic growth, presented sample

[19] Though there were precursors, as Griliches 1995 points out. But Solow=s paper represented watershed progress.

calculations on data for the entire American economy. But the rationale was explicitly microeconomic throughout, and the text contains asides, starting in the very first footnote, and even jokes about the greater appropriateness of micro-level data. The upshot of Solow=s calculation was that the proportion of the growth that could not be explained, and should thus be attributed to technical progress, was very large.

This approach is very apt to the subject and data at hand. It is clear that something happened at Ford. It is clear from Section 3 that the factor inputs were increasing and it is clear that output was increasing more rapidly still. It is clear from Section 2 that this should in a broad sense be identified as technical progress. It is clear from the general literature that both within the industry and in terms of the wider economy this technical progress was epochal; yet it is not at all clear how much of it there was or to what individual innovations, or phase of innovation, different portions of it might be attributed. Such measurement could shed light within and without.

The economic literature subsequent to Solow went off in two directions. One, epitomized by the work of Denison e.g. 1962, was to refine the calculations, generally on post-war data. This was largely an exercise in adding to the list of inputs measured and had the predictable consequence of lessening the size of the residual. But the residual did not go away: no history of the economy, even in the postwar boom years, is complete without an account of its evolutionary course.[20] The second direction, epitomized by the work of Kendrick 1961, involved comparison: pushing backward the initial period to obtain long time series. There was a subsequent movement amongst business consultants and professors to implement total factor productivity measurement on the firm or even plant level as a diagnostic tool.[21] But this was not much noticed by economists, who have not until relatively recently had such datasets to work with.[22]

There are two principle objections to the measurement of technical progress by these methods. One seems to me to be based on misunderstanding a metaphor. The other is, it seems to be, better characterized as a concern of possible relevance. I will argue below that it is not of relevance in this particular case.

The first objection is that the calculation somehow leaves management out of the picture. This seems to me simply to be an excessively literal interpretation of the word Atechnology”. In this context Atechnology@ is used as a synonym for Atechnique,@ a black box relationship between inputs and outputs. Managerial and organizational decisions--and the Toyota Production System, come to that--are part of the technology.

[20] See also the reflections in Section IV of Griliches 1988.

[21] See Hayes and Clark 1985.

[22] Though see e.g. McGuckin 1994.

The second objection is that the standard of comparison is to a world of constant returns to scale production. Some measured total factor productivity growth, on this argument, is nothing but the consequence of increasing returns to scale in a fixed production technology. The force of this complaint depends very much on what is being compared with what. I use these measurement methods to compare an early technology that to a first approximation probably was roughly constant returns to a successor one of whose merits was that it offered increasing returns. So it seems to me that this second objection is not to the point. The added productivity from scale effects here is not a problematic aspect of the procedure. It is a positively desirable feature. The scale effects belong in this residual. They are a central part of what I am trying to measure.

It is also sometimes thought that total factor productivity measurement is somehow invalid if the underlying technology is not Cobb-Douglas. I think this is confused. All means of measuring productivity growth involve the use of index numbers to represent underlying changes. With macroeconomic aggregands i.e. with entry and exit in the underlying population of firms, there will only in the rarest and most implausible of cases be a consistent and exact relationship between the aggregate of microeconomic production relationships and that measurable in the aggregates. The situation is in principle a little more hopeful if one is studying a single firm or factory; but the factory being studied here underwent truly radical changes in its organization during the period under study, and it strains credulity to imagine that the relationships would be stable enough to estimate a production function over a long enough time period to generate a usable number of observations. I find it more helpful to think of this particular index number as being exact in the case of underlying Cobb-Douglas data, as being inexact but at least as plausible as the alternatives in the case of non-Cobb-Douglas data, and as being the only real candidate for comparisons in any case inasmuch as the series to which one would want to compare it themselves are of this form. That is, it is inexact; but it is inexact in precisely the same way as the others are. Using it adds to a comparison only an errors-in-variables problem that may well already be present. Using a different index would leave the waters muddier still.

5. Productivity Growth at Ford as It Appears in the Primary Source Data

Total factor productivity calculations yield both a time series of the total factor productivity index and growth rates. I discuss them in turn. The computations discussed in this section are at the monthly frequency only.

Figure 13 gives the TFP index monthly series from January, 1909, through December, 1914. The most striking feature of the plot may well be how unsteady the progress of the series is. There appears to be a seasonal pattern, with forging forward early in the year and considerable retreat later on. Through the first part of 1914, each year is better than the next. I infer from the massive drop in the latter part of 1914 that the adjustment for capacity utilization is indeed crude and the recession was indeed profound.

--Figure 13 about here--

The next most striking qualitative feature of this series is the absence of explosive growth at any time in the period past the moment the assembly line experiments got under way. The spike in late 1913 is dramatic but not unprecedented in the series. One might be tempted to try to explain this away by invoking the recession: the line offered immense productivity enhancement possibilities, but perhaps slack demand kept the company from realizing them (indeed, quite the contrary). Yet this is an awkward argument given the frequency of the observations. The first five or six months of the year would not have been affected by the macroeconomic events, the attention of mid-level management in the plant was presumably riveted on implementing the new developments, and the publicity attendant on the Five-Dollar Day could only have buoyed up demand. Still, the pattern simply does not suggest the arrival of a new epoch. Nor could it easily be interpreted as showing large productivity consequences to the Five-Dollar Day.[23]

It appears that robust improvement (both on average and peak-to-peak) started very early on.[24] The narrative of Section 2 above suggests attributing this to the slow inroads of American System methods and the brisk ones of progressive assembly. The latter definitely had some play in the Piquette Avenue plant and had greatly enhanced opportunities in the Highland Park Plant.

The developments of the settling-in years at Highland Park relative to what had come before appear substantial. These contributions represent, of course, an interplay between mechanical and organizational innovations on the one hand and the opportunities offered to exploit them intensively on the other.

Figure 13 gives a plot of the Solow residuals corresponding to the levels of Figure 12. Again, the most striking feature of this Figure is how jagged it is. Some of this may well be artifactual, and is in any case familiar from other such high-frequency studies.[25] Yet it is difficult to ignore, or to imagine seeing a principled procedure sweeping entirely away, the feature that the series appears to diminish somewhat in mean and markedly in amplitude as the eye moves from left to right. The dramatic periods

---

[23] This is a point in favor of the interpretation of Raff 1987.

[24] For this reason if no other, it would be very interesting to see the series and computations pushed back before 1906. On the prospects, see the closing paragraph of Appendix Section A2 and especially its accompanying footnote.

[25] On where it might come from, see Appendix Section A2.3.3.4. It might also be an artifact of the reporting period i.e. crucial parts, without which cars could not be completed, often arriving just after rather than just before the end of a month. A well-grounded explanation would be useful. For other high-frequency studies, see Chew 1985 and Hayes and Clark 1985.

may have come later, but the large events seem to have come early on. There is a complementary way of putting this point. It is clear by eye that through the pre-recession part of 1914, the average value of this series is secularly diminishing but consistently positive. The incremental innovations were improving overall productivity i.e. the productivity of all that had come before. But they were adding less and less.

--Figure 14 about here--

The implicit numbers here are large, and very large by the standards macroeconomists and students of economic growth are used to. But both of these facts are just what one should have expected. That the underlying events really did represent a transition from one technology to a more productive one makes the first unsurprising. As to the second, the numbers those groups of scholars study are those of firms aggregated into industries, industries then aggregated into sectors, and, often enough, sectors aggregated into whole economies. If there is much entry and exit of firms going on, the first aggregation can mask large composition effects.[26] The relative rise and decline of industries can have the same effects at the next level up, and the developmental restructuring of the economy at the next level still. Such highly aggregated figures are no guide at all to the study of micro-level phenomena, never mind to the study of a firm marching down the demand curve of a theretofore undiscovered sector. (Recall Figure 2.) The forces governing the dynamics of the more- and less-aggregated growth histories could be very different indeed.

A plot of the minutely ratio of any human's energy output to caloric input would be very jagged. This is not evidence of any inadequacy in measuring the energy or the calories but rather represents a measurement frame that is too fine for the relationships it monitors. The sharp inter-month declines in measured total factor productivity observed in the previous section may well have this character. It thus makes sense to consider the data broken up into longer intervals to see whether the main story of the high-frequency data reappears but reappears more clearly.

Aggregating upwards from fine data is easy (while the reverse is impossible, of course.) A really careful attempt at this sort of analysis would contemplate alternative longer intervals, presumably in part through examining seasonal patterns in production. For the moment, however, I will only consider annual intervals, starting on January 1.

Table 3 gives the results of the total factor productivity calculations on annual data derived by adding up or averaging (as appropriate) the monthly data appropriately. Qualitatively, it shows an uneven but more easily interpreted pattern.

--Table 3 about here--

The year of transition from the old facilities to the purpose-built ones, naturally one of

---

[26] Bresnahan and Raff 1996.

managerial distraction and shop-floor confusion, appears showing a substantial decline of nearly 14 percent. This decline is put entirely in the shade by the first clear year's residual, positive and between three and four times that of the decline. The natural interpretation of this involves exploiting opportunities that had been foreseen and designed into the building. The next year appears as a relative lull--a period of relative consolidation?--though that year's pace is blistering by any familiar standards. The year after that, which includes the tight coupling of sub-assembly production, shows a smaller residual than the peak but still represents a notable burst forward compared to its predecessor. The residual covering the year of the real introduction of moving assemble line is extremely robust by any ordinary standards but comparable in its absolute magnitude to what happened in the disrupted moving year rather than to any of the anni mirabilorum. At the end of the five-year period, the index stands at nearly 2.6. This is progress indeed.

It seems to me that this Table raises two obvious questions for future research. The first concerns how much of this productivity progress derives from ideas and initiatives that were in the air at the time. This is a question best addressed through a decomposition of the industry figures from the Census of Manufactures and through investigations of the performances of other individual manufacturers. Such investigations would need to involve computations parallel to this one as well as reconstructions of their operations history. I have primary source data to allow active pursuit of such research on Studebaker and Packard and hope to report on it in due course.

The second question concerns sequential context. This data is all from a period from the start of which one might imagine that Ford was already thinking big. It would be very interesting to see Table 3's numbers in the context of Ford's transition from artisanal shop. If one is prepared to push the product of indirect labor into the residual (throughout), this appears to be a feasible extension of the paper's calculations. I hope to execute it in the next draft.

6. Other Measures and their Meaning

It is worth delving a little more deeply into what was happening in these years with the evidence presently at hand. Table 4 plots the ratio of hours-adjusted capital (i.e. capital services) to total labor input (in hours). It absolutely does not show the steady and vigorous rise of legend--indeed, its central tendency runs in the other direction. Table 5 even shows that the fall in price could not be accounted for by taking all the labor cost out of the car. Table 6 shows the total labor hours content per car by year. The rise in the transition year to the new factory cannot be very surprising. The subsequent steady and sharp decline is roughly as it appears in legend; but given Table 4, we need to seek an explanation somewhere other than in simple substitution of machines for men. Table 7 suggests that the correct explanation does not lie in the buying in of complete or semi-finished parts. That history does not appear in Table 7 as a simple one, but the trend, where there is one, is in any case going in the wrong direction to explain where the hours are going.[27]

--Tables 4, 5, 6, and 7 about here--

The pattern of inventory holdings is very illuminating, however. Table 8 plots the yearly average real values of mid-month inventories, surely predominantly raw materials and work-in-process (see the Appendix) rather than finished goods, per unit output. There is a substantial spike in this series in 1910, due in the most statistical sense to several unusually low production months and I imagine equally due, as a practical matter, to evolving confusion about how to use the new space. After that, one sees a steady decline tapering off to a level less than half of the initial one. This combined with the timing of productivity growth, suggests that some combination of increasingly tightly coupled stages of production and the rationalization of the paths of materials flow across the shopfloor were very important elements in the overall growth.[28]

--Table 8 about here--

Table 9 is strongly consistent with this interpretation if a principle activity of non-production laborers was materials handling, the tracking down of parts in imminent shortage, and the like.[29] Over the period in question, the ratio of production labor hours input to non-production labor hours falls by more than half. This is, unfortunately, quite an ambiguous statistic. Half of the fall occurs in a year during which the materials content of total costs fell very sharply. Suppose a substantial fraction of the non-production labor tasks concerned bought-in components.

--Table 9 about here--

7. Discussion

The dataset is very valuable. It is an integrated source; it has some documentation; it thus gives reliable data on many topics of interest as well as giving interesting data on a number of topics not hitherto easily researched. It is not yet entirely clear how valuable the high-frequency data are in themselves beyond playing a role in confirming the reasonableness of annual periodization. But the jury

[27] Note that the correct denominator here is unit cost rather than the more easily obtained unit revenue. The two do not necessarily move in parallel.

[28] It is also an excellent example of how inventory holdings can be a useful index of organization change without themselves being an important input into productivity growth.

[29] To the best of my knowledge, there is no evidence whatever as to the balance of their tasks at Ford. The sentence in the text gives a common surmise.

considering that is not yet in.

On some matters of substance, however, some things are much clearer than they were. The time series presented here represents an unusually close look at productivity in a technology transition and shows very dramatic changes in productivity by more or less any standard. The series shows evolving change in productivity--not a single event, nor even an unambiguously monotonic sequence of changes. An obvious interpretation of this starts from the proposition that factories are complex organizations and production processes of durable goods like this simply complex. Change is intricate. Complementarities can be very important but must be managed. (Thus, at least in principle, managers do do something for their pay.) And changes in the external environment can affect measurements such as these.

What did happen at Highland Park? Striking though the cumulative changes were, the details show surprisingly little kick to the advent of the moving assembly line or the Five-Dollar Day, a surprisingly large amount to whatever beginnings of the eventual systems were actively gestating in the closing days of the old-style facility on Piquette Avenue, and lots more kick in (if only intermittently) during the early years at Highland Park. Thus the answer to the question of what happened at Highland Park is ALess than you probably thought and, at that, less what you probably thought it was.@ If something important was finished by the end of 1914, then the contemporary iconography was off as well. It was an important oversimplification to identify mass production with Highland Park. Mass production was certainly not the assembly line. Mass production was not One Big Thing but rather a series of complementary Littler Things.

A metaphor may be helpful. American System methods were the heart of what happened at Ford. And yet even a heart without a circulatory system is just a muscle. And a circulatory system, however healthy, matters little without effective recipient organs for fresh blood and without a nervous system to command them.

One might ask what it all means. In the end, the significance of the events at Ford goes beyond the examples they set for production engineers. The complementarity feature of the innovations meant that piecemeal innovation, however easy, would never replicate the competitive position of the Ford company. To compete against the production system that emerged, it was, roughly speaking, all or nothing. Not for more than a decade after the events described in this paper did a competitor figure out how successfully to do that.[30] The replication of innovation outside the firm, even in an industry that licensed patents freely, is itself a complex and highly contingent process.

[30] See Raff 1991.

APPENDIX: The New Sources and What Has Been Done with the Numbers in Them

A0. The Ur-source

Unlike most works of cliometrics, this one has its material basis in a faintly romantic story. The story seems worth recording.

A0.1. The Additional Tax Suit

The Ford Motor Company was incorporated in 1903 with a par value of $100,000 but, as is well known, with actual paid-in capital of only $28,000.[31] This and the other assets of the company were put up by twelve private shareholders. These were Henry Ford and Alexander Malcolmson (allocated 255 shares each), John S. Gray (105), John W. Anderson, C.H. Bennett, Horace E. Dodge, John F. Dodge, Vernon C. Fry, Horace Rackham, and Albert Strelow (50 each), James Couzens (25), and Charles J. Woodall (10). Grey, previously a successful candy manufacturer and by this stage of his life a bank president, became president of the company.

By the time of the events discussed in the body of the paper, Ford was president and owned 58.5 per cent of the stock. In 1919, the resolution of litigation with the Dodge brothers led Ford to buy out the remaining minority shareholders.[32] A federal Acapital stock tax@ that was in effect at the time had the consequence of making the sellers responsible for tax on the capital gains since 1913. The magnitude of the sale value--over $112 million--gave the Internal Revenue Service a substantial interest in the 1913 valuation, and that interest, in combination with a looming statute of limitations deadline, led to formal proceedings and litigation in the 1920s (the AAdditional Tax Case@).

A0.2. The client, the lawyer, and the disposition of the files

Amongst those pursued by the IRS was a Mrs. Alice Kales, an heir of Gray. She seems to have been fairly well-to-do. But the government also wanted a lot of money. Mrs. Kales was represented by a prominent Detroit attorney by the name of Hal Smith. Later in life, Smith was struck by the thought that the documentation submitted in connection with the case might be of historical

---

[31] See, e.g., Nevins 1954, chapter 11.

[32] The Dodge brothers wanted to set up a competing firm. Ford sought to squelch this by plowing operating profits into the construction of an immense plant on the River Rouge that would embody valuable and intimidating economies of scale. The Dodges sued to make the company disgorge the profits to the shareholders instead. The decision in favor of the Dodges is an important one in the corpus of American corporate law. See Clark 1986 for a full citation and analysis.

interest. He therefore presented the hearing transcripts, five boxes of files, and other oddments including three ledgers to the Detroit Public Library's National Automotive History Collection. There they sat, inventoried and catalogued but thick with dust and growing brittle with age, when I did my thesis research in the summer of 1986. There and thus do they sit still.

A0.3. The contents of the papers

The presented documents comprise a seven-volume set of the court record, five boxes of papers, and four oversized parcels. The boxes contain most of the two-hundred-odd exhibits accompanying the testimony, stipulations by a number of the litigants, and so forth. Some of what is in the boxes is of interest to general historians of the American automobile industry--for example, the depositions of a number of important figures in the industry in the second decade of the century about competitive conditions and the ideas and temperments of individuals--and can be viewed (as it often has been) more easily accessible at the Ford Archives.[33] But some of what is in the boxes definitely does not exist in the Ford Archives and is of significant interest in itself to the the cliometrician, for example a notebook containing onionskin carbons of financial results (including what appears to be a monthly series of gross profits) compiled from the Company=s books by their accountants, Hawkins and Gies. One might wonder how useful such a time series would be by itself. The skepticism is not misplaced. But the series does not stand alone. The oversized parcels need to be examined, and examined more carefully than I did when I was a graduate student.[34]

The first parcel can be dismissed immediately: it is simply a list of the holders of record of common stock as of October 5, 1920. But the others converge on, and, I have latterly discovered, actually attain the status, of real historical treasure troves.

These parcels contain accountant=s ledgers with photostatic copies of monthly statements. The first gives balance sheets and loss-and-gain statements for February 29, 1904, and from May, 1904, through December, 1919. This is intriguing but sounds more illuminating than it is--the balance sheets give a lot of detail to the forms of wealth in which the liquid assets of the Company is held but very little information about directly productive assets. This ledger is about cash flows and cash management. The second ledger contains manufacturing statements running from May, 1904, through September, 1908. These give direct quantitative data and certain summary statistics concerning manufacturing operations. The sheets also give information on branch investments (on which see below.) This is exciting in its promise but not in its coverage: It gives the raw materials for a quantitative portrait of the

[33] For example, the deposition of Nash, which among many others also does exist in the Ford Archives, conveys in a few lines by far the most vivid portrait I know of William Dirant and GM as he ran it.

[34] Also some materials in the boxes. See Section 3 below.

manufacturing side of the business, but does not cover the period of the dramatic changes. The third ledger is really extraordinary, however. Its coverage runs, with only the occasional missing month, from May, 1904, on through 1919. An accompanying affadavit characterizes its contents as follows: monthly manufacturing statements form May, 1904, through September, 1908, excepting only two months; monthly statements of manufacturing operations, branch investments, plant analysis, and plant statistics from October, 1908, through February, 1914 (this is from the inception of Model T production through, roughly speaking, the Five Dollar Day); monthly statements of branch investments, plant analysis and plant statistics from March, 1914, through July, 1916; and monthly statements of analysis of plant and plant statistics from August, 1916, through December, 1918.[35] Accompanying notes of a meeting between IRS officials and the Company accountants clarify Ford definitions and procedures.

Figure A1 reproduces the page for October, 1908, generally thought to have been the first month of commercial production of the Model T. It is in most formal respects a typical page. Note particularly the unusually detailed breakdown of physical assets. It would have been common industry practice to record simply a line item for real estate, plant, and equipment. Instead, the source distinguishes factory equipment, machines, tools, patterns, and even sprinkler systems. Note also the statistics on manufacturing operations. These included a valuation of beginning of period inventory, total hours, average hourly rates, and payrolls for productive and non-productive labor (see Section 3 below for definitions clarifying the distinction), a total number for the men on the payroll, another headcount for the foremen (though this series was not continued for long), salary series for the manufacturing and commercial staff (also not carried through, unfortunately), and totals for monthly materials expenses and manufacturing expenses (the latter a variety of overhead--see McKinsey 1922 or Section A3 below). There is also an accounting of orders, of what was made in the month, and of what of that had, as of the end of the month, gone out to branches, to dealers, and to inventory. There are a number of ratios calculated as quick guides for monitoring operations: factory costs to sales, commercial expense to sales, gain (loss) to sales, manufacturing expense to productive labor, and manufacturing expense to the sum of materials and labor. There are a number of other statistics kept that are of less interest to us concerning, e.g., distribution contracts.

--Figure A1 about here--

One further detail of the page ought also be discussed. The accounting data in the upper right-hand corner on investment in branch plants are not entirely transparent and raise an interesting question

[35] Statement of H.L. Leister of 22 August 1927 accompanying Atrue and photostatic copies of ... records of the Ford Motor Company kept by the ... Company in the regular course of its business,@ Ford Stockholders Tax Case Ledgers. On the provenance of the contents, see AMemorandum of Conference with Mr. Leister, Mr. Hosmer, and Mr. Martindale, by Arthur J. Lacy, at Auditor=s Offices of the Ford Motor Company, on July 13, 1926,@ Ford Archives Accession 96 Box 10.

about how to interpret much of the rest of the data.[36] The block of data gives line items for a series of branch establishments (whose actual activities are discussed in Section 2 below.) The block gives column entries for Book Account, Unearned Profit, Actual Investment, and Interest Earnings. In later years, a finer breakdown of assets, including productive physical assets, is given. The two questions this block raises directly are whether the assets reported include part of the firm=s productive physical capital that should be measured for productivity analysis purposes and whether, conversely, the employees working in these branches are already counted in the measures of labor input referred to above. The question lurking in the background, of course, is AWhat was going on in these establishments?@. There is in fact a question lurking behind that, namely AWho was responsible for it?@. For the fact not to be lost track of is that most of the information on this sheet was there to aid control.

The first background question is addressed in detail in Section 2 below. The conclusions there are consistent with the opinion of the accounting experts I consulted that this partition of accounting information is a natural way to set up accounts when the branches are being regarded as profit centers. This is also consistent with the observation that sales to branches are being accounted for in parallel to sales to (the independently owned) dealers. The Manufacturing Operations and Plant Analysis statistics thus may be taken to bear solely on the mother plant. They do not reflect activity in the branches.

What should be made of all this data? The fruits of this last ledger are of unusual interest for two distinct reasons. The first is that they offer an unusually good and long look at the data firm decision-makers and owners collected and regularly monitored. The second is that they offer the possibility, when combined with the Hawkins and Gies profit figures, of measuring productivity and certain aspects of practice in a fashion that is at once unusually careful relative to the literature on Ford and directly comparable to measures of productivity growth elsewhere in the economy and over time. Their detail reveals on an instant=s reflection the extent to which most of the historiographic literature is about characterizing inputs and actions, leaving assessment of the consequences--that is, all discussion of what the evolution of the input patterns meant in practical terms--to underdetermined inference rather than measurement. At least some of this can now be measured directly. That represents progress.

A1. Which period precisely should be studied?

The paper characterizes various aspects of the evolving production process and then computes total factor productivity at the Ford mother plant, all at a monthly frequency from January, 1909, through December, 1914. A number of decisions about measurement preceded the calculations and are worth discussing explicitly.

---

[36] I am particularly grateful for counsel on how to interpret all of this to Charles Christianson and Sam Parker.

The most obvious of these concerns the choice of period. In the contemporary literature and the traditional historiography, mass production is something that happened in the buildings that Albert Kahn designed for the Ford company and its production ideas in Dearborn, Michigan.[37] These became operational starting in January, 1910. It seemed desirable to start the computations early enough in the history to get some glimpse of what was happening at the earlier site. The starting date of the calculations here is January, 1909, the earliest date for which I have at hand data for all the required variables. I have stopped the calculations at the end of 1914. By this point, the new building, the new system in all its facets, and even the changes in compensation and other labor policies associated with the Five-Dollar Day were all in place. This chronological period fits well with the focus of the labor history and the history of technology literatures. The data do not extend much farther. Operations during much of the further period for the data do exist were dominated by the essentially macroeconomic events of deep recession and then war orders rather than the sort of microeconomic events studied here. Even at that, their interpretation is complicated by other microeconomic developments within the firm, e.g. the development of a local assembly plant system. (See Section A2.2 below.)

I note for the record that it is possible to push the time series for productive labor (only), materials, and manufacturing expense back to May, 1904. It is also possible to estimate the capital stock in at least the main categories bearing on productivity on a monthly basis i.e. one consistent with the later data.[38] I will report on the relevant calculations in the late January draft of this paper.

A2. Measuring output

All measures of productivity are in effect ratios, the numerator being a measure of output and the denominator being an index of some sort measuring inputs. To use this data to study productivity at Ford, then, a decision must be made about how to measure output. This section lays out the considerations.

A2.1. The output of ordinary firms and the output of Ford in the epoch of the Model T

The total factor productivity growth calculations well known to economists aggregate many

---

[37] By Athe traditional historiography@ I mean to indicate studies preceding that of Hounshell.

[38] The Manufacturing Statements for this earlier period give only flows and do not give flows of new investment; but they do give monthly depreciation figures by category. If one is prepared to make assumptions about the depreciation rates being used (e.g. that they were the same as the ones in use in 1913), one could work backward to the stocks. Such depreciation rate assumptions might possibly be validated against annual auditor=s statements, depending upon how far back those go.

products and factories, and often industries and whole sectors. In the face of such aggregation, the question of the distortions introduced by weighting physical output by price seems to have been a small consideration: output markets were simply assumed to be competitive. The issue is not so easily avoided in this case, however. We consider a single factory at any one time, and what was for present purposes an unchanging product throughout.[39] But the firm that ran the factories was throughout the period in question the dominant supplier in its price class; and the power its managers had over its price is a matter of legend as well as fact. The price-taking assumption is clearly untenable. But it is also unnecessary. The calculation requires only proportionate growth rates of something that does not change over time. For this we can simply use physical outputs of the Model T. The ledgers even distinguish manufacturing output from shipments, sparing us the usual difficulties on that score.[40]

This does, as Williams et al. (1993) have noted, raise one potential problem. The Detroit Ledgers tell us that Model T's were shipped either to dealers or to branch plants. In any given month, the sum total of cars shipped was fairly close to the total of cars manufactured. (See Figure A2. The former could be smaller or larger than the latter, of course.) But the balance was not strictly constant. (See Figure A3.) If the work that was done on the fully assembled cars and on the others did not have the same factor proportions, the imbalance will distort these calculations. Without knowing more about the structure of costs or the details of practice, or possibly of both, it is difficult even to assess how big the problem is here.

--Figures A2 and A3 about here--

A2.2. The plant-level organization of production at Ford

The literature on all of this uses phrases such as Abranch plants@ and Abranch assembly plants@ quite loosely. To some extent, this derives from the somewhat self-promotional usage in contemporary company literature. Careful examination of sources in the Ford Archive and of contemporary trade journals reveals the following actual history.

Only in the very earliest years of the company does it seem to have sold directly to individual final consumers.[41] In the period with which this paper is concerned, the Company distributed its output

[39] There were in fact many small changes in the product. (See, e.g., McCalley 1994.) But the issue here is not whether there were engineering changes but whether any of these represented non-trivial changes in the cost structure. My reading of the product history in this period suggests that they did not.

[40] See e.g. Hayes and Clark op. cit.

[41] See Nevins op cit., pp. 240-241, citing the company=s original checkbook (preserved in the Ford Archives). It is interesting to note that the earliest purchasers were doctors. An earlier phase of American medical care!

through a network of regional distributors, which sold both to customers and to dealers, and local dealers. The regional distributors were knows as branches. Starting sometime after 1907, cars were no longer shipped to them in the state in which they were to be sold to customers but were rather shipped in a state requiring some incremental assembly work.[42] The motivation behind this was shipping costs. The Company shipped by rail and paid its fees on the basis of volume (freight cars) rather than weight. It therefore had an incentive to pack the cars densely.[43]

The report of the Assembling Department for 1914-1915 shows a substantial increase in the number of branch plants operating over the year and refers to the plants falling short of output projections Aon account of shortage of Detroit Material@.[44] The sentence implicates two facts, one concerning when the Company began having plants whose job it was to assemble ADetroit Material@ and the other how quickly Detroit learned to supply them. Minutes of the Company=s Board of Directors shed some light on the first of these. The minutes of a meeting on May 1, 1912 discuss buying land on the West Coast Afor the purpose of building thereon suitable buildings for the assembling of our cars out there ... and for the further purpose of giving service to our customers and the general handling of our business ....@[45] But it turns out that just on the West Coast they had in mind purchasing land not only in Los Angeles and San Francisco but also in both Portland and Seattle. It is difficult to imagine that the local demand in such a fine segmentation would support high throughput production methods, which leaves the inference that at least in the early days the branches did some--but relatively artisanally organized--final assembly tasks and mostly devoted their facilities to service and business with dealers and customers. The characterization in the company magazine (distributed chiefly to actual and prospective owners) in November of 1912 takes precisely such a line. It says that A[w]ith a view of the mammoth 1913 production in mind and a desire to increase the efficiency of distribution[,] the Company has established five new branch houses in various parts of the United States. Minneapolis, Portland, Columbus, Charlotte, and Oklahoma City have been selected as the new centers for Ford branch sales rooms and direct distributing points.@ It says nothing whatever about production. The recollection of Wiesmeyer, who spent most of his career laying out Ford assembly plants, that Alayout work for the branches started ... probably around 1915'' is vague but certainly consistent with this picture.[46] (He

---

[42] Nevins, op. cit., p. 345, and Dolnar 1914, p. 130.

[43] Deposition of Norval Hawkins, AIn re Valuation of the Ford Motor Company Stock as of March 1st, 1913: Hearing Before the Solicitor of Internal Revenue, Washington, D.C., June 29-30, 1925,@p. 183, Ford Archives Accession 84 Box 2.

[44] AAssembling Department Report 1914-1915,@ memo by W.S. Knudsen dated August 11, 1915, Ford Archives Accession 1 Box 122.

[45] Ford Archives Accession 85 Box 1.

[46] Reminiscences of Mr. M.L. Wiesmeyer, Ford Archives, p. 19.

thought that the big push to decentralizing final assembly came circa 1922-1923, roughly when the Rouge plant, the giant successor to Highland Park, came on line.) So is the memory of W.L. Hughson, the company=s first dealer and the longtime operator of the San Francisco facility. Hughson recalled in a 1955 interview that the San Francisco branch opened about 1910 (more or less the true date of 1911) but that as of the Panama-Pacific Exposition of 1915, AMr. Ford brought the assembly line to the West Coast for the first time.@[47] If this is all so, it is unsurprising that the company was having trouble in 1914/1915 getting materials to flow smoothly and in the correct proportions to local assembly plants. It had as yet essentially no experience.

What actually happened between Highland Park and the branches in this simpler phase? A reporter named Hugh Dolnar, in a long and detailed automobile trade journal article published in April, 1914, just three months after the Five Dollar Day, writes that A[i]n the case of knock-down shipment the body and the chassis without wheels are sent from Highland Park, while the wheels, tires, lamps, and so on are shipped to the assembling plants [sic] directly from the suppliers, saving a shipping to Highland Park....@[48] He goes on to note, as above, that Ashipping knock-down permits closer loading and so makes a considerable saving in total transportation charges.@ The picture here is thus that in this period Highland Park shipped some completely assembled cars directly to dealers and shipped some knocked down cars to branches for more assembly work prior to either sale or final shipment to local dealers.[49]

A2.3. A glimpse at the figures

The question of detail all this raises for the period in question is how to weight output destined for branches and for dealers so that so that like is being added to like. The larger question is whether the correction makes any difference. It makes sense to address these questions in this order.

The Model T Cost Books shed some light on the first question. These extraordinary documents give unit cost breakdowns (i.e. labor, materials, overhead) for every part and the major sub-assemblies for the Model T on a monthly basis. It would be very interesting to have a continuous run of them from early in the company=s history. Unfortunately, the earliest surviving one is from December, 1913, and the series is irregular in the months immediately following. But December, 1913, is relatively late in the history of the development of production organization at Ford. And costs began, not long thereafter, to be distorted by the recession. So I take figures from that month as representative both because this

---

[47] Reminiscences of Mr. W.L. Highes, Ford Archives, p. 19. The correct dating comes from the files of A.J. Liebling, Ford Archives Accession 96 Box 9.

[48] Dolnar, op. cit.

[49] This is not the picture one gets from Nevins=s text. But Nevins=s text, as we have learned from Hounshell, is not to be relied upon uncritically.

seems reasonable and faute de mieux.

The relevant pages of that Cost Book are reproduced as Figure A4. We can reasonably take the costs of undoing certain assembly operations to be the same as doing them. The most striking thing about these numbers is their small size.

--Figure A4 about here--

The details are as follows. The wheels and tires had to be put on to move the car though the lines and therefore had to be taken off again afterwards. Rear Wheel Assembly is down in the December, 1913, Cost Book at $0.08210 for labor and $0.10919 for overhead.[50] The task of putting the tire proper onto the wheel is not costed out separately and I therefore presume it is included in this figure. Front Wheel Assembly is $0.08702 and $0.11574, respectively. I assume the same treatment for the tires. Taking the wheels off may thus be estimated to add $0.16912 to the labor cost and $0.22483 to overhead, for a grand total increment of $0.39395. On the other hand, nothing in the assembly process turned on the lamps being installed before shipping, and presumably they were therefore left off. The charges on all the items I can find in the Cost Book obviously attributable to the lamps sum to $0.14326 for labor and $0.19052 for overhead, a grand total decrement of $0.33378. These net out at an increment of $0.06017, 0.037 percent of the total cost (as the Company reckoned it) of the chassis and 0.027 percent of the total cost of the car including the body. Even this tiny increment may well be an overestimate since it excludes the cost of any incremental packing materials required when packing the boxcars more tightly. Altogether, this seems to be a distinction without a difference. At this stage, the money was all in the shipping.[51]

In the 1920s, the Company seem to have set up branch assembly plants were designed for volumes on the order of 300 to 500 cars per day.[52] The Department Report of August 11, 1915, states a daily capacity at that time of 1,250 cars with 22 plants [sic] operating.[53] This represents a mean

[50] Model T Cost Book for December, 1913, Ford Archives Accession 125 Box 2. The Wheel Assembly figures cited in this sentence and the next come from Sheet #1 of the Chassis Assembly section. The lamp figures come from Sheet #2. The Touring Car totals come from the unnumbered sheet entitled AMonthly Cost Summary: December, 1913" at the very front end of the book.

[51] Starting in October, 1915, the Cost Books have a separate section for assembling plant parts. In the AGeneral Cost Summary at the front of the book for that month there is, beneath the cost breakdowns for the different models a section giving AShipments in October from the Detroit Plant@ by models. After four body models come the two other listings of Chassis and Manchester Chassis (i.e. chassis bound for the plant in Manchester, England).

[52] Wiesmeyer,op. cit., pp. 32 and 34.

[53] All p. 1.

value of just less than 57 cars per day. Either the optimal daily production rate of a local plant that was doing final assembly as the term was understood in the mother plant increased by an order of magnitude over the decade or the population of plants was at best in transition in 1915. The average floor space of the branches shown in a photographic tableau in Dolnar=s article (p. 127) is 126,005. These buildings all look bright and relatively new and since the photographs almost undoubtedly came from the company, it is reasonable to surmise that they are representative of what the company was building at the time i.e. marginal units of capacity. Wiesmeyer remarks that in the early days they counted on having 700 square foot of space per car per day of expected throughput.[54] By that standard, these buildings would have had an average expected throughput rate of about 180.[55] This is roughly three times the population average over a year later. The modal branches did not have the performance characteristics of the incremental ones. They were old-style operations, and not local assembly plants in the sense we know now.

A2.4. Resolution

This suggests both a weight of the most minor proportions for a weighting procedure and a degree of calm about the whole issue. Productivity numbers could be recomputed with a weighted figure for the output series. But, like Harberger triangles, it would not matter much.

A3. Measuring inputs

In the early (macro) literature on growth decomposition, most of the energy went into refining measures of the inputs. There is no reason not to take such care with genuinely micro data.

A3.1. General remarks

The ledgers in the period in question distinguish four inputs: materials, productive labor, non-productive labor, and capital. General and specific issues arise regarding their use.

A3.1.1. Valuing heterogeneous inputs and the virtues of avoiding this when possible

While Ford is rare in having in this period essentially only one output, it has, like almost all other real world firms, multiple inputs. In total factor productivity accounting, the ideal would be to measure the growth of these inputs in physical terms. Price-like considerations would only enter through the

---

[54] Wiesmeyer, op. cit., p. 34.

[55] Wiesmeyer goes on to remark that at the time of the interview (1955), the allocation had gone up threefold. This suggests that if the 700 square foot number is off for the earlier period, it is too high. That would only strengthen the argument in the text.

cost-weighting terms. The ledgers enable us to calculate cost weights directly or give us the crucial inputs to such calculations.

But prices enter the calculations at least implicitly in two other ways. The first concerns aggregation. Productive labor may be an aggregate that is analytically meaningful. But there are many different jobs with many at least nominally different skill sets subsumed in it. We can either measure the productive labor input as a physical quantity, implicitly setting all the relative factor prices to unity, or we can measure the productive labor input as the productive labor payroll. This would make perfect sense if the factor markets were competitive and paid marginal products. That may conceivably have been true of gross wages at Ford through the end of 1913.[56] It is certainly false in the aftermath of the Five-Dollar Day.

The second way factor prices enter the calculations concerns price change over time. It is clear both that the prices of certain material inputs changed quite considerably over the period in question and that the general level of prices did as well. Something must be done to correct for this.

A3.1.2. When avoiding it is impossible, choosing a price

There is no genuinely well-focused price deflator available for any of the individual inputs, never mind one that is available at a monthly frequency. I make more specific comments as the issue arises below.

A3.2.1. Remarks specifically about labor

The quantities of the labor inputs have previously always been measured lumped together and with a major implicit assumption about quantities. The measure used was man-years. This gives the impression that years represent a fine enough time-partition to reveal the important patterns in productivity change, that the mix of types of work--in particular, the mix between direct and indirect labor--stayed constant, and that the actual hours of labor did not change across years. Any or all of these may be true, but their being false could seriously muddle our picture of what was happening. Each is therefore worth examining carefully. This is now feasible with the new data.

A3.2.1.1. The terms in which to measure labor input

The first question about the labor input that must be addressed is the terms in which it should be measured. The new sources give us a choice between a pure quantity measure (hours) and a price-laden measure (payroll i.e. wL). Hours is clearly better than man-years, which misses both peaks and troughs (see Figure A5.) The merit of using the first of these measures is that the state of competition in

[56] Raff 1987.

the local labor market does not distort the measure of the magnitude of the input. (Market conditions could still, of course, affect the amount of the input desired.) This seems a very important consideration, and physical measures are employed in the computations of this draft.

--Figure A5 about here--

The disadvantage of this physical units approach is that it implicitly assumes that the inputs of labor on all the jobs being aggregated should be weighted equally.[57] It is conventional to argue of the Ford factory in this period that the jobs were becoming all semi-skilled. A more precise version of this assertion concerns the modal job and the fraction of the total that the mode represented. The more precise version is undoubtedly true; and it is worth bearing in mind that the exceptions the more precise version carves out played very important roles in the production process--these were the most highly skilled blue collar employees in the factory, thought to be worth five dollars a day and more even prior to five-dollar day, that is, a time when the modal day wage in the factory was $2.34. The Company clearly thought that these individuals had large marginal products. The next version of this paper will therefore also report value-measures.

I note for reference that when a value measure is used for this input, some correction must be made for the change in price levels over time. There is no obviously suitable index for labor costs that would allow correction for a changing skill premium. (There is nothing close.) The simplest procedure here is to use the WPI. (Fortunately, it is available on a monthly basis.) Some correction is also in order subsequent to December, 1913, to correct for the wage supplements due to the Five-Dollar Day. It is not possible to do this very precisely but crude adjustment is possible and will be implemented in the next draft.

A3.2.1.2. How finely to disaggregate it

There also remains the question of how finely the aggregate labor input should be broken down. The input represented in the man-years figure is broken down in the new sources into productive and non-productive labor. The distinction derives from cost accounting conventions. Productive labor is labor that is involved in directly productive tasks. (It is sometimes more casually referred to as touch labor.) Non-productive labor is everything else in the factory. It includes supervision and support. It therefore includes foremen and shortage-chasers on the one hand and machine-makers, maintenance, and janitorial staff on the other. Non-productive labor is thus an immensely heterogeneous groping. But it is still distinctly different from productive labor, and a shift in the balance between the two or between their relative productivities, might shed light on the nature of what was happening to the organization of production. Table 8 in the text shows the balance was shifting. Thus this disaggregation seems

[57] A deeper problem is that it still doesn=t represent effort. It is presumably closer than so coarse a measure as man-years, however, since it captures at least some of the intensive margin.

potentially worthwhile.

Even more disaggregation would be worth doing, but this is all the data permits. It still represents progress.

A3.2.1.3. Managerial Labor

There is no very satisfactory way of measuring managerial or even quasi-managerial labor input from these sources over the period we wish to study. Foremens= labor is presumably buried within the aggregate of non-production labor, but the source gives no clue how to break it out. Salaried labor poses an additional problem. Even if we had a value for this, we would have to be suspicious as to whether it represented the whole compensation of the individuals in question. At least some held stock.

A3.2.2. Remarks specifically about capital

Deriving figures for capital inputs also requires compromises, but it requires more massaging first. The capital data are not fine enough to satisfy Zvi Griliches (who would like to know about acquisitions and retirements rather than their net effect), but by the ordinary standards of working economists and historians they are remarkably detailed. In an industry in which it was common to have a single line item comprehending real estate, plant, and equipment, the ledgers distinguish, as has been noted, machines from tools. Aside half-a dozen cell entries (filled in by linear interpolation), all entries are present in the ledgers.

A3.2.2.1. The need to redo balance sheet figures

They cannot, unfortunately, simply be lifted directly from source to spreadsheet. There are two problems. The first is that prices for capital goods, like the prices for everything else, undoubtedly fluctuated over the period under study, so that a fixed sum in capital expenditure at different moments the period represented different real purchasing power. The second problem, which interacts with the first, is that capital equipment depreciates with use, and sometimes even simply with the passage of time. This needs to be factored into the creation of a capital stock aggregate and interacted with the price fluctuations. The accountants= depreciation, which values all capital at historic costs and depreciates that, adds muddle to potential muddle.

A3.2.2.2. Deflation (and price deflators)

We must therefore confront once again the need for a deflator. The capital goods being purchased were quite heterogeneous. Some were even custom-made to Ford=s design. It is difficult to imagine a practical procedure for a hedonic price series. As a practical matter, we are reduced to a choice between the WPI and the Bureau of Labor Statistics series for Metal and Metal Products. The latter series is essentially an index of the price of raw materials and producer goods whose production process was highly mechanized (e.g. nails). This is an index very little affected by changes in the cost of skilled labor relative to unskilled. It is obvious examining the components that this is less of a problem, though it still is one, with the WPI. As one might have expected, the two series are not the same. (See Figure A6.) I use the WPI.

--Figure A6 about here--

A3.2.2.3. Depreciation (and depreciation rates)

One familiar reason for being wary of total factor productivity calculations derives not from theoretical subtleties of measuring capital but rather from the practical problems of knowing what firms= conventions actually were.[58] What items are summed up to reach the stated aggregates? What sorts of expenses that might be are not included? This is a huge problem when dealing with aggregates, of course, but it is a nontrivial problem even dealing with the accounts of individual firms. This is particularly so prior to the professionalization of accountancy, but it seems to have remained a problem in cost accounting long after it began to recede in financial accounting.[59]

The simplest solution to the problem with an individual firm turns on to being able to consult whatever internal source (a file, a binder, a looseleaf notebook: generically, a handbook) was used to keep track of conventions and their evolution as operating circumstances and issues evolved. No such handbook exists contemporaneous to the Ford Motor Company=s early days, and nothing of the sort of any vintage exists in the Ford Archives. But Smith=s files contain notes entitled ADescription of Accounting Procedures@ that seem to be just what is required.[60] The main import of that document for the measurement of capital is that depreciation was booked as a manufacturing expense.

How should the relatively finely distinguished and unambiguously undepreciated capital figures be depreciated? Categories broad enough to have motivated someone to calculate a distinct depreciation rate ought to be depreciated separately. Correspondence between Ford accountants and the IRS in the early 1920s display the IRS asking why Ford does not use certain standard rates the IRS has suggested and being told that Ford had conducted its own measurements and come to different

[58] See e.g. U.S. Department of Commerce Bureau of the Census 1923.

[59] On accountancy, see Miranti 1990. The establishment of the Securities and Exchange Commission was also an impetus towards the standardization of financial accounting definitions and conventions. But cost (sometimes Amanagerial@) accounting is done for internal consumption only.

[60] Box No. 5. These appear to report a meeting between IRS officials and senior Ford accountants in which the government men were asking precisely these questions.

conclusions.[61] The differences seem plausible, given the peculiarities of Ford practice relative to what one imagines to have been average practice in the American industry of the day, so I have adopted the Ford rates. Some aggregation of the ledger sheet categories was necessary but straightforward. I ended up using seven categories. Depreciation was calculated by the perpetual inventory method.[62] As explained in the preceding paragraph, I used the WPI, faute de mieux, to deflate the values of the investment flows.

A3.2.2.4. Matching stocks of correctly measured capital be matched to flows of cooperant factors

The question next arises of how to match data on stocks, such as physical capital, with data on flows, such as labor hours. It seemed to me that pairing flows over a period with a terminal value of stocks was inappropriate, the desired quantity, being the quantum of the stock to which the flow is being applied. The mean level of the stock over the period seemed a better approximation, and that is what the calculations use.

A3.2.2.4. How quickly does correctly measured capital become productive?

One must also at least implicitly make a decision as to when new physical capital should be considered to become productive. A balance sheet records the time at which ownership commences. It is plausible that this is roughly when the equipment arrives at the establishment. But is this when the equipment begins to render valuable service? Is new equipment never at first largely in the way? Do operators and managers immediately understand how to use it efficiently? Optimally? In the rapidly changing environment of the Ford company, it is plausible that most capital equipment was ordered for immediate use rather than for stock. How soon was it successfully deployed? How quickly was it as useful as it came to be? The standard computational procedures imply immediate usefulness. Chew's 1985 thesis documents that a lag better measured in months than in days is sometimes a more accurate picture. The data at hand are insufficiently stable to estimate the relationship. It is possible that an

[61] See Craig to Commissioner of Internal Revenue, May 20, 1929, and Departmental Communication (Zellmer to Martindale), April 30, 1934, both Ford Archives Accession 157, Box 187.

[62] This is not an uncontroversial way of proceeding. It has at least the merit of being standard practice, in particular relative to the studies with which the ultimate figures will be compared. But the model it presents of physical depreciation is that the stock of services flowing from a machine (that may itself embody technical progress) degrades steadily over time. An alternative model that might be relevant to a factory in the throes of rapid technical change is one in which a substantial part of embodiable technical progress is happening on a much faster timescale than the machines wear out. Machines might be replaced before any measurable wearing out because machines of superior ex ante capabilities are becoming available. The perpetual inventory method would not be appropriate in this case. I do not see how to decide, on the evidence available, in which world Ford was in.

alternative estimate with a lag structure should accompany the main estimates. If the true lag is not degenerate, the procedure I do use overestimates the stock of capital in each period and assumes that it depreciates too quickly. The net effect of the two with varying patterns of net investment is not clear a priori.[63]

A3.2.2.5. How much productive capital is actually in use?

There is the further complication that given a level of efficiency at any moment, the full capacity of the equipment may not be available. There are several margins at which factor utilization can be varied. For capital equipment, the most obvious one is hours. This seemed easy to correct for, yielding a measure reflecting the actual flow of capital services. Relatively precise information about hours, workdays per week, and shift numbers appears in Nevins.[64] This plus a universal calendar permits the calculation of a series giving factory hours per month, all of course on the assumptions of no overtime and equal shift lengths and numbers across departments.[65] The assumption may not be true, but my present view is that the calculation is not far wrong. The assumption is clearly much better than the next-best alternative.

A3.2.2.6. The user cost of capital

There are some purposes for which the capital figure one wants is not the input per se but the user cost of it, for example in creating unit cost breakdowns. The Company=s own series (Manufacturing Expense--see the remark above) includes correction for depreciation but does not--oddly, as a matter of logic--incorporate any consideration of the cost of owning the capital equipment in the first place. To the extent that this breakdown is interesting because the company calculated and presumably consulted it, no correction is in order. To the extent that it has any theoretical interest, the correction should be done.

There is at least one reason to want an economically meaningful figure. The validity of a calculation of total factor productivity whose measure of output is anything other than value added will

---

[63] It is not at all clear what to do about this (potential) problem. Griliches notes that the news is not all bad: there is only one direction for the lag to extend. And it is implausible that it would have lasted for many months. But how many? In what pattern? And in the absence of an estimation procedure, what should one do with sensitivity analyses that turn out to show small and not obviously nonlinear differences? I do intend to carry out sensitivity calculations and do not expect that they will induce significant differences in the growth rates. But the whole situation is unattractively ad hoc.

[64] See pp. 371, 384, and 524-525, p. 524, and pp. 375 and 532 respectively.

[65] Nevins=s facts will of course need to be checked against such relevant primary sources as survive.

be undermined by changing degrees of vertical integration. How might this be measured? One standard way is to consider the time path of the fraction of materials expenses in total revenue. But if price and therefore total revenue is a variable, quit likely subject to strategic choice, it is not at all clear how much meaning should be attributed to this. A sounder procedure would be to use total economic cost for the numerator. The index this produces would not be a powerful test over all domains: if the stock of productive capital went up, so too would user costs; and even ceteris paribus, the index would fall. On the other hand, if the stock of productive capital was rising (ex hypothesi and in the facts of the Ford case as well) and the value of the index actually rose, this would be powerful evidence that more of the output was being bought in. The index seems worth creating, and I will include it in the next draft.

Doing this means correcting the company=s overhead figures. The proper correction procedure would have two parts. The first would be to calculate from the ledgers and subtract off from the overhead figure the unit depreciation as the Company would have figured it, adding back in a unit depreciation figure calculated on the lines suggested above. Secondly, one should add in the product of an appropriate interest rate times the total value of the capital stock (unadjusted for capacity utilization, since the larger figure is the burden to be born.) The appropriate interest would be the opportunity cost of funds to the firm on a monthly basis. It is difficult to know precisely what maturity is an appropriate comparison and precisely what risk class of debt instrument would be in order, but the alternatives are in fact thin: the only real alternative to a series on government debt is the monthly series for high-grade industrials in Homer and Sylla 1991 (Table 45, p. 342).

A3.2.2.7 Manufacturing expense strictly so called

As an afterthought to the above, it may be worth noting what precisely was included in the manufacturing expense figure. The subcategories are engineering and supervision (where the former includes the miscellaneous expenses of running the engineering operation down to drafting supplies and the latter includes all supplies, expenses, and salaries attaching to the factory office as well as the salaries of manufacturing officials, superintendents, and foremen), power (i.e. energy transmission and generation), material transport and storage (including inspection and testing as well as equipment maintenance), heat and light, special process heat, direct production expense (maintenance of machinery, durable and small tools, and patterns and unchargeable direct labor), inefficiency expenses (downtime, demurrage), buildings and land maintenance, fire and personal injury protection, relief and welfare work (once relevant), and a miscellaneous category including alterations, experimental work, factory taxes, and water rates. Whether or not depreciation is included according to this memo turns on the interpretation of the significance of a paragraph indentation, but it is perfectly obvious from the early manufacturing statements in the ledger that depreciation was included.

A3.2.3. Remarks specifically about materials

Materials expense is given i.e. as a value. A price deflator is obviously required. The calculations have been performed deflating materials bills by the WPI. I intend to experiment with using the MMP series to see how much difference it makes. (The problem here is different from the problem with choosing a deflator for capital goods. Still and all, the cars were not made entirely out of metal.) I do not expect the difference to be great.

A3.2.4. Remarks specifically about entrepreneurial returns

Finally, entrepreneurial returns require measurement for economic unit cost breakdowns and equally to calculate a proper return to capital for cost-share-weighting in the productivity growth calculations. The Detroit Public Library materials include a summary of monthly accounting statements giving earnings that had been submitted by the firm's accountants, Hawkins and Gies, in the Additional Tax Suit in Detroit Public Library boxes.[66] These figures appeared to be gross profits and I used them as such.

A3.2.5. Remarks specifically about energy

The classic works of productivity measurement such as Solow 1957, unlike some more recent studies, do not consider energy as a factor of production. Some more recent datasets make this possible. It would have been interesting in this period to be able to do so, since this is a period of transition from belt-driven machines to stand-alones and from public provision ot power to private. But the data do not survive. They were collected, at least through 1908. But they do not survive for the period for which the other data does.

A3.2.6. Remarks specifically about inventories

Finally, consideration should be given to the data on inventories. What can be made of them? In principle, some types of inventories are reasonably regarded as a factor of production. Buffer stocks, for example, keep a tightly coupled system from having to stand idle when an upstream station has to stop functioning for a short enough period. But there are other ways of organizing the productive system such that buffers are themselves a type of anti-factor: in one well-known view, it is precisely the property just cited that keeps the managers from recognizing small problems getting bigger.

The argument about how to think about buffers may be moot here. It is not yet possible for me to tell from the ledgers or other documents I have seen precisely what is comprehended in these inventory figures. They may well include final goods inventories as well as work-in-process. The

[66] Box 3.

errors-in-variables problems introduced might thus be very large. I therefore leave inventories out of the productivity calculations entirely. The time series history is discussed in the text and displayed, at annual frequency, in Table 7.

TABLE 1

Sales of Ford Cars (Nevins Appendix III)

Period	Vehicles	Notes
1903-1904	1 700	
1904-1905	1 745	
1905-1906	1 599	
1906-1907	8 423	
1907-1908	6 398	
1908-1909	10 607	
1909-1910	18 664	
1910-1911	34 528	
1911-1912	78 440	
1912-1913	168 304	
1913-1914	248 307	
1914-1915	221 805	(10 months)

Source: Nevins 1954, p. 644, citing Secretary=s annual reports for 1903-1904 and 1904-1905 and Athe Special Data File of the Ford Motor Company@ for the rest. Note that for most of the period covered the company=s fiscal year began in October.

TABLE 2

Model T Prices and Production

Price	Production
$950	19,173
850	9,450
780	35,451
690	68,228
600	151,693
550	180,279
490	185,278

NB: Prices are in nominal dollars.

TABLE 3

Total Factor Productivity at Ford: Annual Basis

Period	Solow Residual	Index
1909-10	-0.136	1
1910-11	+0.566	0.86
1911-12	+0.333	1.35
1912-13	+0.436	1.80
1913-14	+0.186	2.59

TABLE 4

<u>Adjusted Capital-Labor Ratio</u>

Year	Ratio
1909	3.38
1910	4.26
1911	3.73
1912	2.84
1913	1.76
1914	2.98

The ratios reported here are means of ratios for each month of the year in question. The numerator of the monthly ratio is the product of the deflated depreciated value of the mid-month capital stock and an index measuring the number of hours the factory was open that month. (See the Appendix for the sources behind the hours computation.) This product proxies the flow of capital services. The numerator is the sum of production and non-production labor hours worked during the month in question.

TABLE 5

Labor Cost per Unit Output

Year Payroll per Car	Production Labor Payroll per Car	Total Labor
1909	$ 45.62	$ 73.17
1910	59.99	106.15
1911	35.98	56.12
1912	37.03	63.75
1913	33.86	61.23
1914	46.10	94.52

TABLE 6

Total Labor Hours per Unit Output

Year	Hours per car
1909	339.89
1910	435.37
1911	245.45
1912	257.43
1913	230.64
1914	166.18

TABLE 7

Materials Share in Total Cost

Year	Materials/Total Cost
1909	0.82
1910	0.76
1911	0.82
1912	0.79
1913	0.77
1914	0.57

Note that the figures for the denominator in this ratio are preliminary.

TABLE 8

Real Dollars of Inventory per Unit Output

Year	Inventory per Unit Output
1909	$1430.67
1910	2030.38
1911	736.95
1912	635.81
1913	532.81
1914	561.52

TABLE 9

Ratio of Production- to Non-Production Labor Hours

Year	Ratio
1909	1.90
1910	1.45
1911	1.97
1912	1.53
1913	1.31
1914	0.89

BIBLIOGRAPHY

American Society of Mechanical Engineers Sub-Committee on Machine Shop Practice. 1912. Developments in Machine Shop Practice during the Last Decade. Transactions of the American Society of Mechanical Engineers 34:847-865.

Arnold, Horace, and Fay L. Faurote. 1915. Ford Methods and the Ford Shops. New York: Engineering Magazine.

Ashton, T. S. 1948. The Industrial Revolution 1760-1830. London: Oxford University Press.

Braverman, Harry. 1974. Labor and Monopoly Capital: The Degradation of Work inthe Twentieth

Century. New York: Monthly Review Press.

Bresnahan, Timothy F., and Daniel M.G. Raff. 1996. Technological Heterogeneity, Adjustment Costs, and the Dynamics of Plant Shutdown Behavior: The American Auomobile Industry in the Time of the Great Depression. Working Paper No. 96-05. Philadelphia: Wharton School Reginald Jones Center.

Chew, W. Bruce. 1985. Productivity and Change: The Short-Term Effects of Investment on Factory-Level Productivity. Unpublished Harvard University Ph.D. dissertation.

Clark, Robert C. 1986. Corporate Law. Boston: Little, Brown.

Colvin, Fred H. 1913a. Building an Automobile Every Forty Seconds. American Machinist 38: 757-762.

Colvin, Fred H. 1913b. Machining the Ford Cylinders I. American Machinist 38:841-846.

Colvin, Fred H. 1913c. Ford Crank Cases and Transmission Covers. American Machinist 39: 49-53.

Colvin, Fred H. 1913d. Special Machines for Auto Small Parts. American Machinist 39: 439-443.

Colvin, Fred H. n.d. Automobiles. Box 3. Fred H. Colvin Papers. Freiberger Library. Case Western Reserve University. Cleveland, Ohio.

Dension, Edward. 1962. The Sources of Economic Growth in the United States and the Alternatives Before Us. Supplementary Paper No. 13. New York: Committee for Economic Development.

Ford Archives. Edison Institute, Greenfield Village, Dearborn, Michigan.

Ford Stockholders Tax Case. National Automotive History Collection. Detroit Public Library. Detroit, Michigan.

Griliches, Zvi. 1988. Hedonic Price Indices and the Measurement of Capital and Productivity: Some Historical Reflections. Working Paper No. 2634. Cambridge: National Bureau of Economic Research.

Griliches, Zvi. 1995. The Discovery of the Residual: An Historical Note. Working Paper No. 5348. Cambridge: National Bureau of Economic Research.

Hayes, Robert H., and Kim B. Clark. 1985. Exploring the Sources of Productivity Differences at the Factory Level. In Kim B. Clark, Robert H. Hayes, and Christopher Lorenz, eds., The Uneasy Alliance: Managing the Productivity-Technology Dilemma. Boston: Harvard Business School Press.

Helper, Susan. 1991. Strategy and Irreversibility in Supplier Relations: The Case of the U.S. Automobile Industry. Business History Review 65:781-824.

Homer, Sidney, and Richard Sylla. 1991. A History of Interest Rates (Third edition). New Brunswick: Rutgers University Press.

Hounshell, David A. 1984. From the American System to Mass Production: The Development of Manufacturing Technology in the United States. Baltimore: Johns Hopkins University Press.

Kendrick, John W. 1961. Productivity Trends in the United States. Princeton: Princeton University Press for the National Bureau of Economic Research.

Lewchuk, Wayne. 1987. American Technology and the British Motor Vehicle Industry. New York: Cambridge University Press.

Mayr, Otto, and Robert C. Post. 1982. Yankee Enterprise: The Rise of the American System of Manufactures. Washington: Smithsonian Institution Press.

McCalley, Bruce W. 1994. Model T: The Car that Changed the World. Iola: Krause.

McKinsey, James O. 1922. Budgetary Control. New York: Ronald Press.

McGuckin, Robert. 1994. Annual Report of the Center for Economic Studies. Suitland: U.S. Bureau of the Census.

Meyer, Stephen. 1981. The Five-Dollar Day: Labor, Management, and Social Control in the Ford Motor Company, 1908-1921. Albany: State University of New York Press.

Milgrom, Paul, and John Roberts. 1993. The Economics of Modern Manufacturing: Technology, Strategy, and Organization. American Economic Review 80:511-528.

Miranti, Paul. 1990. Accountancy Comes of Age: The Development of an American Profession. Chapel Hill: University of North Carolina Press.

Nevins, Allan. 1954. Ford: The Times, the Man, the Company. New York: Charles Scribner=s Sons.

Rae, John. 1959. American Automobile Manufacturers. Philadelphia: Chilton.

Raff, Daniel M.G. 1987. Wage Determination Theory and the Five-Dollar Day at Ford. Unpublished Massachusetts Institute of Technology Ph.D. dissertation.

Raff, Daniel M.G. 1991. Making Cars and Making Money in the 1920s: Economies of Scale, Economies of Scope, and the Manufacturing behind the Marketing. Business History Review 65:721-753.

Raff, Daniel M.G. 1996. Productivity Growth at Ford: A Preliminary Analysis. Business and Economic History .

Raff, Daniel M.G., and Mannuel Trajtenberg. 1997. Quality-Adjusted Prices for the American Automobile Industry 1906-1940. In Timothy F. Bresnahan and Robert J. Gordon. New Goods: History, Theory, and Measurement. Chicago: University of Chicago Press for the National Bureau of Economic Research.

Raff, Daniel M.G., and Manuel Trajtenberg. Manuscript in progress.

Rosenberg, Nathan. 1963. Technological Change in the Machine Tool Industry 1840-1910. Journal of Economic History 23: 414-443.

Rosenberg, Nathan, ed. 1969. The American System of Manufactures: The Report of the Committee on the Machinery of the United States 1855 and the Special Reports of George Wallis and Joseph Whitworth 1854. Edinburgh: Edinburgh University Press.

Smith, Merritt Roe. 1977. Harpers Ferry Armory and the New Technology. Ithaca: Cornell University Press.

Solow, Robert M. 1957. Technical Change and the Aggregate Production Function. Review of Economics and Statistics. 39:312-320.

Sorenson, Charles F. 1956. My Forty Years with Ford. New York: Norton.

Sward, Keith. 1948. The Legend of Henry Ford. New York: Holt, Reinhart, and Winston.

Tedlow, Richard. 1990. New and Improved: A History of Mass Marketing in America. New York: Basic Books.

Thomas, Robert Paul. An Analysis of the Pattern of Growth of the Automobile Industry 1895-1929. 1977. New York: Arno Press.

U.S. Department of Commerce Bureau of the Census. 1923. Fourteenth Census of the United States. Manufactures. Washington: United States Government Printing Office.

U.S. Department of Commerce Bureau of the Census. 1933. Fifteenth Census of the United States.

Manufactures. Washington: United States Government Printing Office.

U.S. Department of Labor Bureau of Labor Statistics. 1915. Bulletin No. 181: Wholesale Prices 1890-1914. Washington: United States Government Printing Office.

Warren, G.F., and F.A.Pearson. 1937. Wholesale Prices in the United States for 135 Years, 1797 to 1932. In Cornell University Agricultural Experiment Station. Wholesale Prices for 213 Years, 1720 to 1932. Ithaca: Cornell University Press.

Williams, Karel, Colin Haslam, and John Williams. 1992. Ford versus >Fordism@: The Beginning of Mass Production?. Work, Employment, and Society 6:4, 517-555.

Williams, Karel, Colin Haslam, and John Williams. 1993. The Myth of the Line: Ford's Production of the Model T at Highland Park, 1909-1916. Business History 35:3, 66-87.