From production to profit: an extended lab report: from a simple experiment in production

Jonathan Willner

Abstract: One of the many difficulties in teaching economics is convincing students that short-run production and cost measurements are tightly and inexorably linked and that they matter to profitability. From a discussion of production and costs we usually move right on to profit maximization at the margin in a perfectly competitive environment. An intermediate step would focus on how elasticity and cost measurements influence profits. Most introductory texts discuss the links between production and costs as well as the relationship between elasticity of demand and total revenue. Students often come away from the experience without connecting these essential concepts. Using an experiment designed by Ted Bergstrom and John Miller, I develop a lab report that leads the student through short-run productivity measurements and relationships (from Bergstrom & Miller, 1997), cost measurement and relationships, the links between production and cost measurements and finally how production and cost targeting may influence profits in the absence of direct knowledge of revenues. This last set of connections depends simply on demand elasticity as opposed to market structure and its plethora of assumptions.

Introduction

When Colander (2000) wrote, “We economists... are dynamic, exciting individuals and the stories we have to tell are fascinating...” we economists must have all gotten quite a chuckle. In the face of considerable evidence of failure, it is often useful to have a laugh at one’s self. While the laughter provides some relief, we are left with the basic problem, put succinctly by Hansen, Salemi & Siegfried (2002), “Taking a high-school or college economics course has little impact on economic understanding.” In other words, our time-tested teaching methods aren’t working.

Lucas (2002, p. 473) is quite emphatic about economic understanding, writing “economic illiteracy often is an affliction of the well-educated.” If the educated do not know economics but have taken a course in economics, then teaching did not occur.

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Hansen, et al, (2002) suggest a reduction in content coverage as a solution to the current problem of limited learning. Others suggest that the approach to presenting the material needs to be changed.

Becker and Watts (1996) show that economists still use almost exclusively the lecture approach in attempting to teach. Their work leads to the suggestion that changing the delivery of material would lead to improved learning. Becker and Watts (1999) provide many examples of alternative presentation methods. Emerson and Taylor (2004) provide evidence that using experiments in a principles course leads to improved learning as measured by concurrent tests.

Instead of redesigning entire courses or introducing a new approach to delivering the message of economics, I have chosen a smaller task – connect the dots and don’t make large jumps while using experiments that have been shown to improve learning. As we recall from graduate school – if there are large jumps, the models don’t tend to generalize well. Much the same can be said for teaching these models.

This paper is a bit of a guide book on how to, hopefully, reverse the abysmal performance of economics learning by undergraduate students by providing a sound understanding of how business functions in general. There are two main features emphasized with the approach taken here. The first is improvement in the understanding of the connection between production measurements and cost measurements. The second is introducing an intellectual step that precedes the entire market models approach by linking costs with elasticity, total revenue and changes in profits. In the situations provided here the assumed positive relationship between labor productivity and profits is demonstrated as conditional as is the assumed link between lower average total costs and profits.

The aforementioned situations are analogous to two buzzword, one-size-fits-all, approaches to basic business problems. In the first case, enhancing labor productivity to increase profits is shown, by experimental experience to be dependent upon demand conditions – elasticity and its relationship to total revenue. In the second case, the reduction of unit costs is also shown not to have a direct link to profits. Again the
dependence is upon demand conditions. It hopes to help replace that approach with one based on a well understood process, where “depends” is an essential and useful word. The approach has lead to a number of cases of students recognizing the reasons why so many simple business bestseller list ideas fail so often.

**Background and Development**

The basis for the work rests with Bergstrom and Miller (1997, pp. 271-282). In this part of their text, students build paper airplanes and track production as the number of people per factory increases. This successfully generates the standard Average Product (AP) and Marginal Product (MP) short-run production functions. Bergstrom and Miller provide a laboratory report form that develops the methods of calculation for various measures of production and productivity.

Based on strictly personal and other anecdotal evidence², laboratory or experimental approaches in the classroom increase student interest during the class meetings. More relevant to our mission, evidence is accumulating that experiments in classrooms increase student learning. For example, Emerson and Taylor (2004) found that microeconomic understanding, as measured by TUCE scores, was greater in sections using experiments. Dickie (2006), using TUCE in a pre and post test approach found similar results for experiments as an in-class teaching approach. Durham, McKinnon and Schulman (2007) do not use TUCE as an outcome measure. They use a large data set and examine both micro and macroeconomics courses. They find positive effects on questions dealing with topics covered through the use of experiments.

In the typical introductory economics text, after several pages of short-run production writing, there are several pages dealing with short-run cost functions and how they are generated from production measures. Authors such as Miller (2004), Colander (2004), Baumol & Blinder (2004) and Sexton (2005) use this approach. The alternative is that the two related ideas are separated into consecutive chapters such as

² For example, Bergstrom & Miller, 2000 vi, note “they [students] are enthusiastic about what they are doing.

At this point, rather than jump to market models, which is the standard approach, I introduce an intermediate step that joins production/cost ideas with elasticity/total revenue ideas. In virtually all texts, elasticity includes the relationship between elasticity of demand and TR and precedes discussion of production. Rather than dealing with popular notions and intermediate ideas, economists tend to jump immediately to profit maximizing at the margin under a long list of assumptions.

The approach taken here is to deal with popular concepts and misconceptions while integrating the material from two to three chapters. Doing this does not require extensive assumptions nor does it require new material. The purpose is to help connect the ideas of production, costs, elasticity and profits before introducing the more complex conditions associated with specific market models. The same experiment is used, but is extended across this entire range of ideas with emphasis on popular buzzword solutions. Particular buzzword concepts that have been poorly implemented for a variety of reasons (whether through willful ignorance, intentional misrepresentation or poor education is not relevant here) are “downsizing”, “productivity” and “economies of scale.” This latter term is popularly confused by paying scant heed to its specific meaning in economics; the time/input choice issue is routinely ignored in favor of simply seeing the issue as one of volume of production.

Appendix 1 contains a modified version of the entire lab report as developed from Bergstrom & Miller (1997). The version expands considerably on their work, but the basic structure is dependent on their work.

**Process & Experience**

Between 12 and 24 students were involved in each section where this version of the lab report was used. Students were given two minutes to build as many complete

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3 Among these are variations on, number of consumers, number of producers, product homogeneity, absence of entry barriers, time horizon, information structure and absence of increasing returns to scale. The specifics phrasing and number of assumptions is largely dependent on the text author’s discretion.
paper airplanes, to specifications, as possible. Capital is a pen and defines a factory. After several rounds of one-person factories, in which learning-by-doing is demonstrated, there are two-minute rounds of airplane building with increasing labor per factory. The lab report is then completed in class.

The combination of airplane building and lab report completion in-class may take two or three class sessions depending on the format of the sections taught. I provide no lectures on the subject of calculating short-run production or cost measurements. Students appear to “learn-by-doing” much of what I used to lecture on for these chapter(s).

The actual building of airplanes may be accomplished in a single 50 minute class meeting. The lab report completion may take more than an additional 50 minutes. The amount of time necessary depends on the size, inherent ability and preparation of the students. At first glance this seems like a great deal of class time. However, the airplane building and lab report cover short-run production, short-run costs, how they are related and extend that into decisions and calculations of profitable decision making. Students are advised to read the appropriate production and cost chapters before building airplanes. Little preparatory lecture is provided, rather the discussions with students during the lab report work informs the students of the issues associated with measuring and calculating. In answering the lab report, students have a strong tendency to reference their textbook.

Some students may take the initiative to complete the lab report outside of class. This often results in repeated errors and a great deal of frustration for students. Most, if not all, textbooks have tables of short-run production and short-run costs as homework questions much like the lab report. Any professor who assigns these problems has noted that these are often assignments that create difficulty for students.

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4 This deviates from the Bergstrom & Miller approach. They advocate having students learn to build the airplanes at home before the actual experiment. After several attempts at this experiment it became obvious that the data of interest was corrupted by heterogeneous labor quality. Using the learn-by-doing approach in class assures more homogeneous labor quality and provides data (output and wasted material) for discussion the learn-by-doing approach to manufacturing. Learn-by-doing is another buzzword solution that can be examined with this experiment.
when completed outside of class. Since repeated errors tend to be ingrained, these difficulties significantly impairs learning. We have to first un-teach that which they have learned and then teach them the proper method for calculation production and cost measures.\(^5\) The in-class approach mitigates these problems. Faculty who choose to adopt this approach to teaching short-run production and cost measurement will necessarily have to decide the appropriateness of the trade-offs faced in terms of time spent on different issues and student learning. The literature, noted above, supports the notion that experiments enhance learning.

The first part of the Lab Report is virtually identical to Bergstrom & Miller (1997). If students have read the required portion of the text on AP and MP, there is little need for intervention by the faculty member. This is a basic, common exercise to most introductory texts. However, unlike many texts the numbers are not designed to generate whole number answers.

The next step is to identify various parts of the table that are often focused on in textbooks: diminishing MP and maximum AP. This is also the point where more common terminology is brought in. AP is commonly referred to as “labor productivity”. Use of this term is often reserved for macroeconomic and/or labor sections of a text. If we fail to introduce this terminology, students do not recognize the table or exercises as related to actual business practice.\(^6\) Rarely in both the experiment and in business, will there be a whole number that capture the point where MP=AP, hence, this experiment provides ample opportunity to discuss measurement issues, etc.

When textbook authors move from production to cost functions, they tend to use whole numbers and smooth functions. This is understandable, however it does not comport well with what is observed in the experiment (When was the last time any of us saw a data set that was perfectly normal with only whole numbers?). The lab report insists that the numbers we started with be used to the end. Production is the source of

\(^5\) Consider the effect of the “snowplow” technique as a teaching tool in skiing. After learning it, to progress you must unlearn it. This increases the time necessary to learn the more advanced, “parallel” method of skiing.

\(^6\) This also provides an opportunity to discuss the implications of MP vs. AP as appropriate measures of labor productivity.
costs. If we hope for our students to understand this, we should show them how it works, not simply claim it works. Of course this means the dreaded decimal point or, even worse to the students (but much preferred by this faculty member) fractions appear in the calculations of various cost measures.

The lab report has wage and rental rates provided. The students next calculate the costs that we economists so frequently discuss, but on a per-average-firm basis. Experiential learning seems to help here, so that some of the calculations are actually learned by the students. It is important to point out that Average Variable Cost (AVC) is, in this case, unit labor costs. “Unit labor cost” is both more familiar and more descriptive than AVC. Generalizing to other inputs will be easier if the students see the process working on an understood input. Average Total Cost (ATC), in economic parlance, is referred to as “unit cost” for the same reasons. Again students who have done the assigned readings will be able to do the calculations, but walking through the room to help is advisable.

In both the production and cost graphs, the comparison to book graphics opens the door to data analysis and tendencies as opposed to certainties. Smoothness disappears – no class will produce perfectly smooth curves. There are occasional bounces up or down in the graphs. All of these provide an excellent opportunity to deal with data and its interpretation – i.e. model building and testing. The fact that the generated data will create patterns very much like the stylized graphs used in economic theory provides an opportunity to discuss the nature of the relationship between theory and evidence.

The final step in the Lab Report is to associate costs (production and costs have been linked) with demand elasticity and profits. The students should be familiar with the idea that profits can be written either as:

- profit = TR – TC or
- profit = (P – ATC)*q

where P = price and q = firm production.
The students are asked to find the level of output that minimizes unit costs. From there they are asked to adjust output to improve labor productivity. This is similar to the simple form of downsizing where the common idea was that reducing the labor force increases labor productivity and increasing labor productivity increases profits.

In order to achieve higher labor productivity, the students will have to reduce the labor used. There is a strong tendency in freshman and sophomores not to understand tables. Many students will want to choose labor and production and any given measure of costs from cells as opposed to rows. Once they understand using the table, students are asked to gauge the impact on profits (↑, ↓, ↔, ?) that result depending on elasticity of demand. I provide four scenarios: price is constant (perfectly elastic as in perfectly competitive markets, but they don’t have to deal with all the assumptions), demand is elastic, unit elastic or inelastic in response to firm behavior. These questions require multiple step reasoning and incorporation of production, costs, elasticity, TR and profits in one continuous question – much like they might confront in a business. For example, laying off some labor, given that the amount used minimized ATC is the appropriate response to the above request. This will decrease TC but increase ATC while achieving the desired increase in labor productivity. This is important since many students fail to distinguish these related measures of costs and this provides an opportunity to learn the importance of these differences. AP (labor productivity) is now higher - the first part of downsizing holds, but some problems associated with profitability are becoming obvious – ambiguity is rearing its ugly head.

Now suppose that price is unaffected by firm production. Reduced production means lower TR and lower TC, suggesting that profit changes are unknown. However, given price is fixed and ATC is higher, profits are necessarily lower (profit equation 1).

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7 There is considerable debate in economics about the “price taking” model. Experimental economists, Vernon Smith (see Smith, 1982) in particular, have argued and demonstrated that markets will tend towards equilibrium in the absence of many of the highly restrictive assumptions associated with perfectly competitive markets as delineated in textbooks. I use the result of the “price taking” model without delving into the source of this result. The underlying assumptions associated with “price taking” come after elasticity, production and costs in all texts with which I am familiar. As no model leading to this outcome is necessary to postulate the situation, I provide none to the students.

8 How many times have you heard something like, “increasing production reduces costs”? What students probably (hopefully?) mean by this is, “increasing production reduces ATC.”
Thus, in this case, downsizing has increased productivity but lowered profits. If demand is inelastic then profits will increase (profit equation 2). The second section of profit analysis reverses the choice of production/labor.

**Aggregate Results**

The experiment has been run, by me, on over 28 occasions with various class sizes and locations including England, Singapore and China as well as the United States. The experiment should run until the marginal product of labor becomes zero or negative. Over time I found that it was necessary to eliminate certain size firms to reach a natural stopping time during a 50 minute class. I also found that when firms were of labor size 8 marginal product was extremely close to 0 (0.56 on average for all experiments in the data set), so I expected to run the experiment a minimum of 8 times after the “learn-by-doing” sessions. I dropped labor size 5 and labor size 7 to avoid a rushed result.

Firms of labor size 5 were also problematic in my data set. In the 13 times I ran the experiment with these size firms the standard deviation for marginal product was the largest, though it’s mean value was the smallest. This is a consequence of 3 results with very large negative marginal products which I attribute to error on my part in controlling the experiment.

Chart 1 shows the mean results of AP and MP where I exclude experiments where firms of labor size 5 existed. Chart 2 shows how including results for firms of labor size 5 distorts the typical graph of short-run labor production measures.

CHART 1 HERE

CHART 2 HERE

As the data is being generated, it is important to control for excessive deviations from normal. In other words, I look for sudden jumps into negative marginal
productivity. Absent a jump down in marginal productivity at a very small firm size, I continue the experiment until 0 or negative marginal productivity occurs; usually at about the 8 worker per firm size.

Using the data from Chart 1 and providing a wage rate of $10 and a capital cost of $50 Chart 3 is generated with the typical short-run cost curves so popular in economics. As with production measures, the individual experiment cost curves may have less than perfect form.

Using the aggregate data provided in Appendix 2 to answer the Lab Report is direct. The concern is with noting the direction of change in profits. For example, if a firm started where unit costs were as low as possible, it would have to produce 13.37 units of the product at unit costs (ATC) of $6.73. Improving labor productivity (I usually suggest maximizing AP) would mean laying off one worker. This would lead to higher unit costs (now $7.81), but lower unit labor costs (now $2.93 vs. $2.99). It is important to emphasize this failure of the two measures of costs to move in the same direction.

CHART 3 HERE

The next step is to tie production changes and the associated cost changes to existing material on elasticity and total revenue, not to marginal analysis – that comes later. In a perfectly competitive short-run model the firm experiences perfectly elastic demand. However, that level of thinking is not yet required. If for whatever reason, demand is perfectly elastic then the price does not change with the level of production. A production decrease (from 13.37 to 10.24) means less product is sold. Given a fixed price, total revenue has declined. Many students will jump to the idea that total costs have declined as well. This would lead them to argue for ambiguity of profit changes.

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9 Negative marginal product has the advantage of creating great turmoil when calculating marginal costs. This turmoil is an opportunity for students to become more numerate – to understand the meaning of the calculations, not simply how to calculate.

10 The assumptions necessary for perfect competition are extensive, and for these purposes, irrelevant. This is more a consideration which can be phrased easily as, “suppose demand is perfectly elastic as was suggested in Chapter...”.
However, the profit per unit is lower and unit sales are lower as well, so profits are unambiguously lower.

**Conclusion**

The extended lab report takes students through a series of connected ideas using problem solving based on their own activities. Students become aware of the essential connections between production/productivity measures and costs/productivity measures. A brief list of these connections is as follows:

1. Maximum $\text{MP}_L$ occurs where $\text{MC}$ is minimized and vice versa;
2. Maximum $\text{AP}_L$ occurs where $\text{AVC}$ is minimize and vice versa; and
3. ATC may be declining while $\text{MC}$ and $\text{AVC}$ are increasing.

The third connection listed above is essential to understanding the nature of costs. Students also gain an understanding of how simple answers to productivity changes often do not exist. Efforts to enhance labor productivity may increase unit costs, despite increasing labor productivity. Further, enhancing labor productivity may not increase profits and lowering labor productivity may increase profits. These last two relationships are essential for student comprehension of the ambiguity associated with choosing activity levels with only one part of profitability in mind.

Once students have seen and experienced some of the complexities of movements in production, costs, and revenues, the idea of choosing production to maximize profits is no longer so difficult. Since few assumptions are used in the Lab Report (a condition on demand is given as opposed to an entire market structure assumed) students are not faced with a complex number of interacting conditions. This allows them to focus on the steps at hand – an intermediate consideration on the way to developing an understanding of different market models and the marginal approach.

We economists have, for decades, tried to model business practice with almost embarrassing results in terms of communicating these to the general public. Business schools routinely require students to take microeconomics as part of the curriculum. Much of microeconomics deals with basic business conditions – costs, productivity,
profitable decision making. While we economists look at many more areas of society, in those areas so close to immediate business practice it would seem appropriate to our objectives as teachers to provide a more effective learning experience for all our students.

Business best sellers often provide flawed and simplistic notions of how to improve profitability. These books capture imaginations, sell volumes and lead to occasionally positive results for businesses (the wave of downsizing is one example). Unfortunately, these books’ even more common failures lead business to adopt the next simple notion, not to an understanding of economics.

This Lab Report is an effort to increase the likelihood that buzzword solutions will not be adopted. Rather, the difficult but functional view of how economies and businesses work will come to be adopted. Of course, this means speaking the language of the typical business person rather than the syntax of the typical fascinating economist! It is a small thing to describe Average Total Cost and then use it interchangeably with “unit cost”, which is more in line with the vernacular.

There is no effort to establish an equilibrium, short- or long-run, in this experiment. However, my experience is that it provides excellent opportunity to discuss long-run issues. Once the students have generated their own short-run cost functions they seem to grasp immediately what increasing the number of pens would do – at low target levels of production (1 or 2 person factories) it would have no effect on production, but would increase ATC. This provides a natural segue into long-run cost functions.
References


Appendix 1

Working as a group (sign below) answer the following questions. Submit a neatly written answer set. One answer set per group.

1) Fill in the chart below with data generated in class after learning-by-doing occurred (adjust the Labor per firm in the columns to fit what happened)

<table>
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<tr>
<th>Number of Firms</th>
<th>Labor per firm</th>
<th>Industry production</th>
<th>TP = Q (average firm)</th>
<th>AP_L (average firm)</th>
<th>MP_L (average firm)</th>
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2) From this point on using only TP, AP_L and MP_L of the average firm to answer questions. What level of labor:
   a) Has the highest MP_L? What is TP at that level of labor? What is MP_L at that level of labor? What is AP_L at that level of labor?

   \[ L = \ldots, \quad TP = \ldots, \quad MP_L = \ldots, \quad AP_L = \ldots \]

   b) Has the highest AP_L? What is TP at that level of labor? What is MP_L at that level of labor? What is AP_L at that level of labor?

   \[ L = \ldots, \quad TP = \ldots, \quad MP_L = \ldots, \quad AP_L = \ldots \]

   c) Has the highest TP? What is TP at that level of labor? What is MP_L at that level of labor? What is AP_L at that level of labor?

   \[ L = \ldots, \quad TP = \ldots, \quad MP_L = \ldots, \quad AP_L = \ldots \]
3) Graph $AP_L$ and $MP_L$. Do they match the textbook description?

4) Use the data above and assume that each unit of capital (pen) used costs $50 and that wages (per unit of labor) are $10 to complete the following table (adjust entries to fit class performance).

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<th>TP = Q</th>
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<th>ATC</th>
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6) What level of production:
   
a) Has the lowest $MC$? What is the lowest $MC$? How much labor is used at that level of production? What is $AVC$ at that level of production? What is $ATC$ at that level of production? What is $MP_L$ at that level of production? What is $AP_L$ at that level of production?

$$Q = \text{______}, \quad MC = \text{______}, \quad L = \text{______}, \quad AVC = \text{______}, \quad ATC = \text{______}, \quad MP_L = \text{______}, \quad AP_L = \text{______}$$

b) Has the lowest $AVC$? What is the lowest $AVC$? How much labor is used at that level of production? What is $MC$ at that level of production? What is $ATC$ at that level of production?
level of production? What is $\text{MP}_L$ at that level of production? What is $\text{AP}_L$ at that level of production?

$Q = \text{______}, \ MC = \text{______}, \ L = \text{______}, \ AVC = \text{______}, \ ATC = \text{______}, \ MP_L = \text{______}, \ AP_L = \text{______}$

c) Has the lowest ATC? What is the lowest ATC? How much labor is used at that level of production? What is $\text{AVC}$ at that level of production? What is $\text{MC}$ at that level of production? What is $\text{MP}_L$ at that level of production? What is $\text{AP}_L$ at that level of production?

$Q = \text{______}, \ MC = \text{______}, \ L = \text{______}, \ AVC = \text{______}, \ ATC = \text{______}, \ MP_L = \text{______}, \ AP_L = \text{______}$

7) Graph $\text{AVC}$, $\text{MC}$ and $\text{ATC}$. Do they match the textbook description? Explain.
8) Suppose you are operating at a level of production that minimizes ATC and you are ordered to increase labor productivity (APL).
   a) How do you adjust your labor usage to maximize APL?
   b) If the price you sell the product for is fixed at some initial value, what happens to profits as labor productivity increases? Explain.
   c) If the price of your product changes with quantity sold (we assume you sell everything you produce) according to the law of demand, and demand is elastic what happens to your profits? Explain.
   d) If the price of your product changes with quantity sold (we assume you sell everything you produce), according to the law of demand, and demand is unit elastic what happens to your profits? Explain.
   e) If the price of your product changes with quantity sold (we assume you sell everything you produce), according to the law of demand, and demand is inelastic what happens to your profits? Explain.

9) Suppose you are operating at a level of production that maximizes labor productivity (APL) and you are ordered to decrease ATC.
   a) How do you adjust your labor usage to achieve the lowest possible level of ATC?
   b) If the price you sell the product for is fixed at some initial value, what happens to profits as ATC decreases? Explain.
   c) If the price of your product changes with quantity sold (we assume you sell everything you produce) according to the law of demand, and demand is elastic what happens to your profits? Explain.
   d) If the price of your product changes with quantity sold (we assume you sell everything you produce), according to the law of demand, and demand is unit elastic what happens to your profits? Explain.
   e) If the price of your product changes with quantity sold (we assume you sell everything you produce), according to the law of demand, and demand is inelastic what happens to your profits? Explain.
### Appendix 2

#### Aggregate Data

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Charts and Figures

Chart 1: Mean Production Results

Chart 2: Mean Production Results