Staff Paper

**Analysis of Projects with Price Effects,
and Application to Innovation and Technical Change**

**by
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Abstract

This paper provides an introduction to benefit-cost analysis of projects with price effects, intended for use in teaching. The impact of price changes on consumers' and producers' surplus under competitive market assumptions is presented graphically with linked numerical examples. The effect of demand and supply shifts on social surplus is then discussed, distinguishing the shift effect holding price constant from the price effects themselves. The distribution of gains and losses to consumers and producers is also evaluated. The analysis is then extended to include distortions such as price supports and ceiling prices. Applications to the evaluation of agricultural research impacts are then introduced, drawing on recent literature. An illustrative exercise based on maize research in Zambia is included.

23 pages

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Analysis of Projects with Price Effects,
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1. Introduction to BCA of projects with price effects.

Much of what we have done to date consists of project analysis in the sense of Gittinger (1982): the project is not assumed to affect prices. Gittinger expands:

> Project analysis is a species of what economists call "partial analysis." Normally, we assume that the projects themselves are too small in relation to the whole economy to have a significant effect on prices. In many cases, however, a proposed project is relatively large in relation to a national or regional economy. In this event we must adjust our assumptions about future price levels to take account of the impact of the project itself. ...Much more elaborate analytical procedures than those discussed here must then be called into play... (p. 10).

Fortunately, there is a considerable literature on measuring the effect of price changes on social welfare. We draw on this literature to develop measures of benefits and costs that include the effects of price changes. These measures are not overly elaborate.

The determination of project benefits and costs when prices change consist of two parts: calculating the project's impact on prices, and calculating the impact of price changes on social welfare. We shall attack first the issue of the impact of changes on social welfare.

The approach taken to analyze the impact of price changes on social welfare is still one of partial analysis. That is, the focus is on a single agricultural market. Applied welfare economics is used to determine the effects of price changes on consumer, producer and social welfare. References include, Mishan (1981), Sugden and Williams (1978, Tolley, Thomas and Wong (1982), and Tsakok (1990).

The causal attribution of price changes to individual projects is more idiosyncratic. The price policy literature has little to say on this issue, since price policies are generally designed to have fairly transparent effects. For example, a food subsidy to urban consumers may be designed to lower the price of food, and for political reasons the government usually makes sure that this is widely known. Irrigation, road, and other projects may have less obvious effects on prices. Two standard ways of calculating the price reductions associated with development projects are through enterprise budgets and through partial equilibrium analysis.

The enterprise budget is an analog of the farm budget (Gittinger, 1982, pp. 127-40), but applies to any productive enterprise. Gittinger states that "When a farm budget for project analysis is prepared, the objective is an estimate of the incremental net benefit arising on the farm as a result of the project (p. 127)." This approach implicitly holds the output price constant. Lower production costs with constant output price will result in greater net farm income; this change in net farm income is the incremental net benefit noted by Gittinger. For example, in Gittinger's Paraguay case, farm production costs are reduced (after an initial investment period) by farmer investment in land improvement, farm construction, farm equipment, and livestock. An alternative assumption is that some of this cost reduction is passed on to the consumer in the form of lower prices. Lower output prices for agricultural products reduce the net incremental benefit to farmers over what would happen in the presence of fixed output prices, but the project valuation now includes a positive incremental net benefit to consumers.

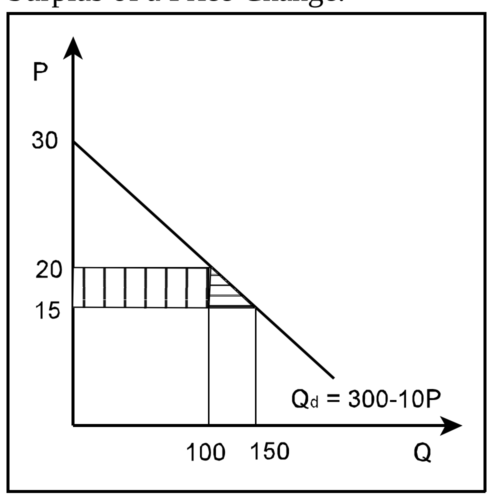
A second, standard approach to the valuation of projects with price impacts is partial equilibrium analysis. In its simplest form, partial equilibrium analysis measures the project effects as a shift(s) in the supply or demand curves. These curves and their shifts can be used directly in applied welfare calculations of project benefits. This approach, known as applied welfare analysis, is the one that we shall take. The particular examples we give will focus on agricultural technology, but the tools used have a much broader application.

2. Applied Welfare Analysis of Price Changes

a. Consumers' surplus

"Consumers' surplus is the value to consumers of the opportunity to buy ... a good at a particular price (see Sugden and Williams, p. 116)." The change in consumers' surplus due to a project is the value to consumers of the opportunity to buy a good at the post-project price less the value to consumers of the opportunity to buy the good at the pre-project price. Diagrammatically, the change in consumers' surplus is the area between the demand curve and the vertical axis, bounded by the with and without-project prices (Figure 1).

Figure 1. Effects on Consumers' Surplus of a Price Change.

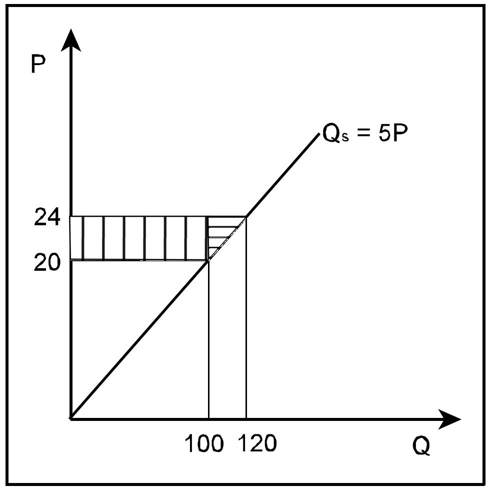


Numerical Example: Without-project case: assume $Q_d = 300-10P$, $P = 20$. Then $Q_d(30) = 0$ and $Q_d(20) = 100$. Consumers' surplus (CS) is $CS = \frac{1}{2}\times100\times(30-20) = 500$. Now suppose that the project changes the price to $P_e' = 15$. Then $Q_d(15) = 150$ and the new consumers' surplus, CS', is $CS' = \frac{1}{2}\times150\times(30-15) = 1125$. The change in consumers' surplus (ΔCS) can be calculated by comparison of the with- and without-project scenarios, $\Delta CS = CS'-CS$. It can also be calculated directly, as the area bounded by the vertical axis, the two price lines $P = 20$ and $P = 15$, and the demand curve. This area can be calculated as the sum of the area of a rectangle and a triangle. So, $\Delta CS = (20-15)\times100 + (20-15)\times\frac{1}{2}\times(150-100) = \mathbf{625}$.

b. Producers' surplus

Reasoning analogously, producers' surplus is the value to producers of being able to sell a particular good at a particular price. The change in producers' surplus due to a project is the value to producers of the opportunity to sell the good at the with-project price less the value to producers of the opportunity to sell the good at the without-project price. Diagrammatically, the change in producers' surplus is the area between the supply curve and the vertical axis, bounded by the with- and without-project prices (Figure 2).

Figure 2. Change in Producers' Surplus with Price Increase.



Numerical Example: Without-project case: assume that $Q_s(P) = 5P$. $P_e = 20$. Then $Q_s(0) = 0$ and $Q_s(20) = 100$. Producers' surplus (PS) is PS = ½×20×100 = 1000. Now suppose that the project changes the price to $P' = 24$. $Q_s(24) = 120$, and $PS' = ½×24×120 = 1440$. $\Delta PS = PS' - PS =$ **440**. The change in producers' surplus can also be calculated directly as the area between the vertical axis, the two price lines P = 20 and P = 24, and the demand curve. This area can be calculated as the sum of the area of a rectangle and a triangle: ΔPS = (24-20)×100 + (24-20)×½×(120-100) = 440.

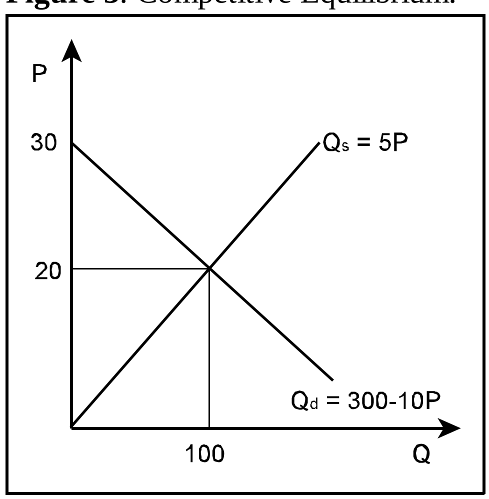
c. Competitive equilibrium

Supply Curve: $Q_s = S(P)$. Shows quantity supplied as a function of price. Also, marginal cost of production.
Demand Curve: $Q_d = D(P)$. Shows quantity demanded as a function of price. Also, marginal value of consumption.
Equilibrium: $Q_s = Q_d$. Price adjusts to insure that quantity demanded equals quantity supplied.

Numerical Example #1:
$Q_d = 300 - 10P$, $Q_s = 5P$. $P_e = 20$; $Q_e = 100$ (Figure 3)

Numerical Example #2: $Q_s = 5P^{0.9}$; $Q_d = 100P^{-0.1}$.
$Q_s = Q_d \Rightarrow 5P^{0.9} = 100P^{-0.1}$. $P_e = 20$, $Q_e = 74.1$.

Figure 3. Competitive Equilibrium.



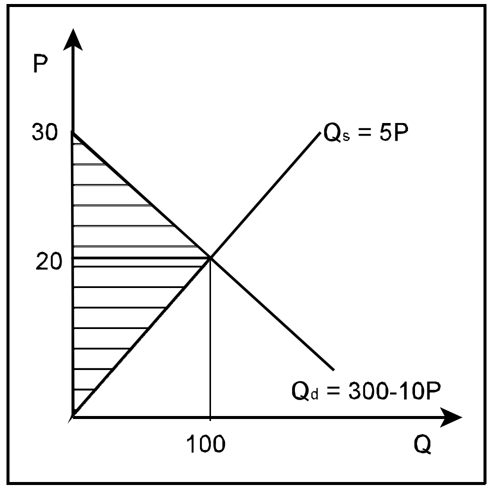
d. Social surplus

Social surplus is the sum of producers' and consumers' surplus. It represents the gains to society from the production, trade and consumption of the particular good being examined.

Diagrammatically, social surplus is represented by the area bounded by the supply and demand curves and the vertical axis (in a competitive market). (See Figure 4.)

Numerical Example: Q_s = 5P, Q_d = 300-10P. P_e = 20, Q_e = 100, social surplus (SS) = ½×30 ×100 = **1,500**.

Figure 4. Social Surplus.



3. Applied Welfare Analysis of Demand and Supply Shifts

a. Effect of demand shift, assuming price is held constant

Demand shifts. Consumers' surplus changes due to the demand shift. Within the context of project analysis, demand might shift if the project itself increases demand (particularly with respect to project inputs), or if the project introduces a higher quality product to the production system and consumers shift their demand because of the higher quality. Holding prices constant, the change in consumers' surplus is the area between the demand curves and above the line P = P_e. There is also a price effect, as the demand shift increases the equilibrium price.

Numerical Example: (See Figure 5.) Q_d = 300-10P.
P = 20, Q_d(20) = 100. Q_d' = 360-10P. The height of the demand shift is calculated at the intercepts:
0 = $Q_d \Rightarrow P_d$ = 30, 0 = $Q_d' \Rightarrow P_d'$ = 36. Height = 36-30 = 6.
Q_d' (20) = 360-10×20 = 160. Holding price constant, the demand shift effect on consumers' surplus is the horizontally barred area:

6×½×(160+100) = **780**.

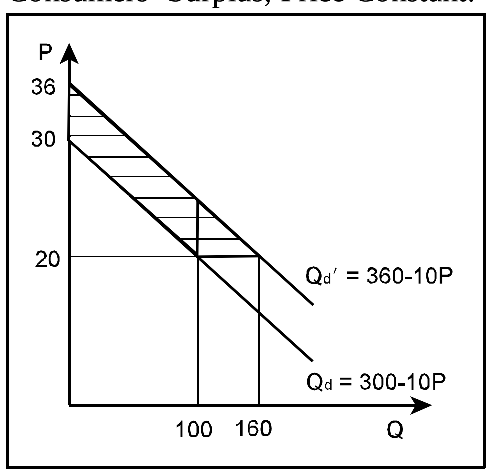
This can also be calculated as a large (new) minus a small (old) CS triangle:

½×(36-20)×160 - ½×(30-20)×100 = 780.

Or, as a parallelogram + triangle:

6×100 + ½×6 × (160-100) = 780.

Figure 5. Demand Shift Effects on Consumers' Surplus, Price Constant.

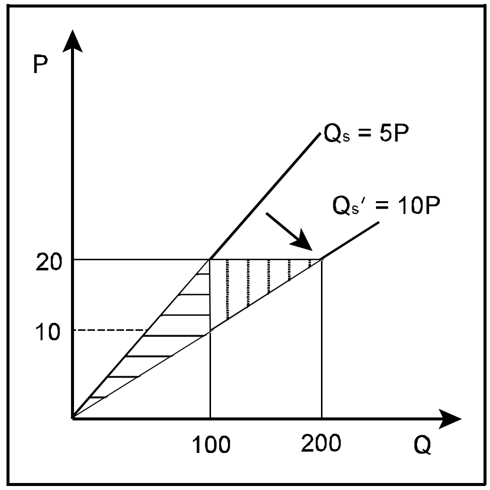


b. Effect of supply shift, assuming price is held constant

Supply shift. The change in consumers' surplus due to the supply shift is the area between the supply curves and below the line $P = P_e$. The effect on producers' surplus can be disaggregated into (a) the effect of the supply shift, holding price constant, and (b) the effect of the price decline resulting from the supply shift. We will focus here on the first effect, shown in Figure 6.

Numerical Example: $Q_s = 5P$, $Q_d = 300\text{-}10P$, $Q_s' = 10P$. $P_e = 20$, $Q_e = 100$. At $P_e = 20$, $Q_s' = 200$. Effect (a) = ½×100×10 + ½×(200-100)×10 = 500 + 500 = 1,000. The first term is the triangle with horizontal fill lines; the second term is the triangle with vertical fill lines. The area of the combined triangle can be estimated directly as: ½×(200-100)×20 = 1,000.

Figure 6. Effects on Producers' Surplus of a Supply Shift, Holding Price Constant.



c. Aggregate effect of demand shift on social surplus

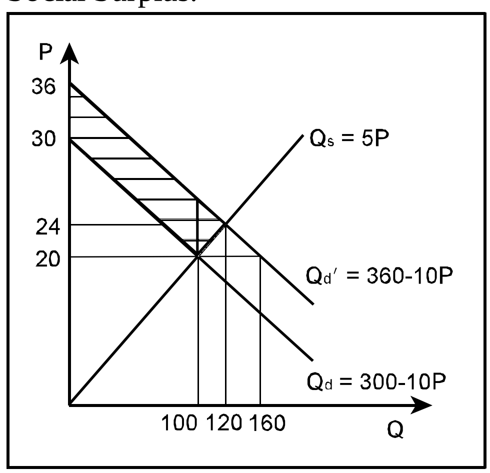
$Q_d' = 360\text{-}10P$; $P_d' = 24$, $Q_d' = 120$. Change in SS = shaded area = 6×½×(100+120) = **660**; or (parallelogram + triangle): 6×100 + ½×6×20 = 660. (See Figure 7.)

The same change in social surplus can be calculated by summing the following three effects:

1) Effect of shift in demand, holding price constant;
2) Effect of price rise on quantity demanded;
3) Effect of price rise on quantity supplied.

- Effect (1) was calculated above as 780 (see Figure 5).

Figure 7. Effect of Demand Shift on Social Surplus.



• Effect (2) is calculated as follows, given that the rise in equilibrium price from 20 to 24 causes a reduction in quantity demanded from 160 to 120 (Figure 8). The reduction in consumers' surplus is:
(24-20)×½×(160+120) = **560**.
Or, (24-20)×120 +½×(24-20)×(160-120)
= 480 + 80 = 560.

• Effect (3) is calculated as follows, given that the rise in equilibrium price from 20 to 24 increases the quantity supplied from 100 to 120 (Figure 9). The increase in producers' surplus is:
(120-100)×½×(20+24) = 20×½×44 = **440**. Or, (24-20)×100 + ½×(24-20)×(120-100)
= 400 + 40 = 440.

• The total effect is 780 - 560 + 440 = **660**, the same amount calculated at the beginning of this section.

Figure 8. Effect of Price Rise on Demand and Consumers' Surplus

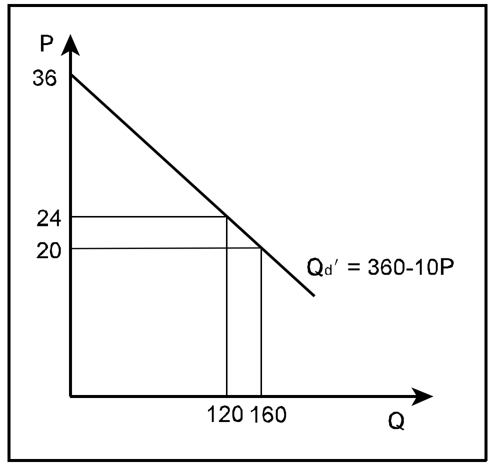
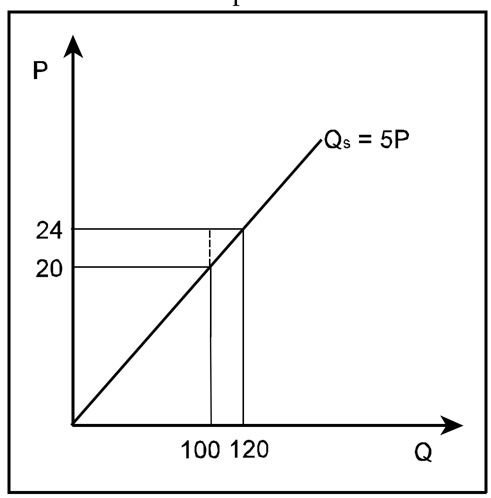


Figure 9. Effect of Price Rise on Supply and Producers' Surplus



d. Aggregate effect of supply shift on social surplus

Assume that the supply curve shifts from $Q_s = 5P$ to $Q_s{}' = 10P$. Demand stays the same at $Q_d = 300 - 10P$. As indicated in Figure 10, the equilibrium price falls from 20 to 15, and the equilibrium output rises from 100 to 150.

The changes in surplus measures are as follows:

• Change in consumers' surplus:
(20-15)×100+½×(20-15)×(150-100) = **625**
Or, (20-15)×½×(150+100) = 625

• Change in producers' surplus:
½×15×150 - ½×20 ×100 = 1125 - 1000 = **125**
Or, ½×(150-75)×15 - [(5×75)+(½×5×25)] = 125

• Change in social surplus: 625 + 125 = **750**[1]

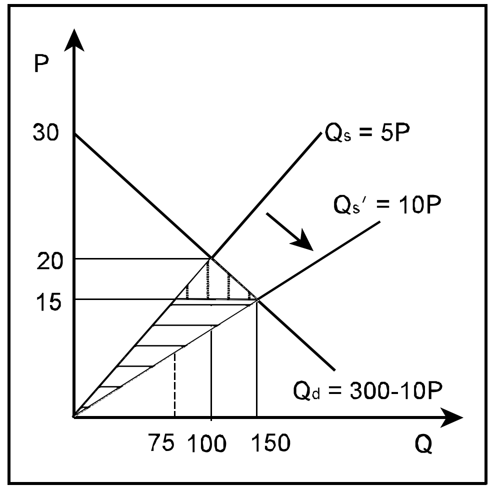
[1]The effect of the supply shift holding P constant = 1,000. The effect of the price decline is to reduce Q_d from 200 to 150, and to reduce PS by ½×(200-100)(20-15) = 50 × 5 = **250**. So the net effect is 1,000 - 250 = **750**.

• If you are not interested in the changes in consumers' and producers' surplus, you can calculate the change in social surplus directly as SS′ - SS (Figure 10):

½×30×150 - ½×30×100 = 2250 - 1500 = **750**

• Or, you can calculate the area of the shaded triangle in Figure 10 as the area of the horizontally barred triangle plus the area of the vertically barred triangle: ½×(150-75)×15 + ½×(150-75)×(20-15) = 562.5 + 187.5 = 750.

Figure 10. Effect of Pivotal Supply Shift on Social Surplus

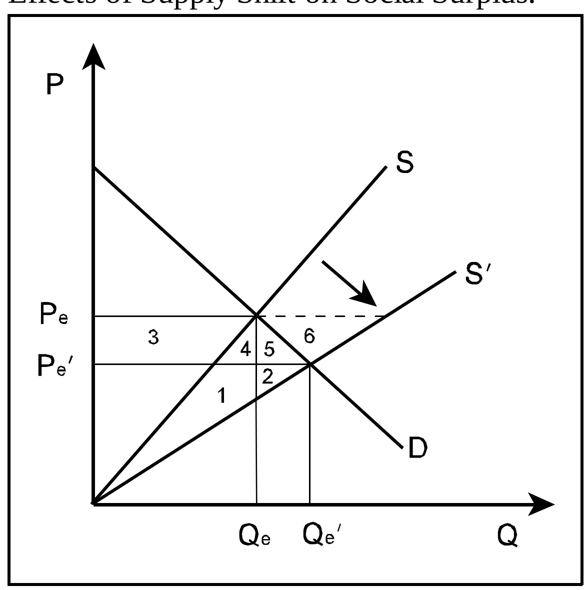


e. Direct calculation of impacts on social surplus

The approach we have taken—of breaking down the effects of supply or demand shifts into the effects of the shift holding prices constant plus the price effects on consumers and producers—is useful for project analysis. First, it allows for more general analysis of projects, including those which shift supply or demand without affecting price, for example by shifting supply of an export good in a small country. Second, it allows for analysis of marketing 'projects'—such as pan-territorial pricing, fertilizer subsidies, urban food subsidies, etc.—through their price effects, even if these projects do not shift the supply or demand curve. Third, the decomposition is important in the attribution of benefits to various components of a project. For example, a project that researches and develops innovative agricultural inputs, and then subsidizes the price of the outputs produced, has price effects arising both from the supply shift due to the R&D and from the output price subsidy. It may be useful to decompose these various effects.

The economic literature on applied welfare analysis often approaches the effect of supply and demand shifts by calculating producers' and consumers' surplus directly, rather than by decomposing the effects into a shift effect and a price effect. We will show how, for a supply shift, the conventionally measured change in producers' surplus is equal to the sum of our two effects. In either approach, the only effect of the supply shift on consumers' surplus arises from the price effect. An analogous construction can be made for a demand shift.

Figure 11. Decomposition of Shift and Price Effects of Supply Shift on Social Surplus.



The various geometric shapes of interest are numbered in Figure 11 and summarized in Table 1 below. The shift effect of the supply shift, holding price constant, is 1+2+4+5+6. The price effect on producers is -(3+4+5+6), where the negative sign reflects the fact that price declined. The net effect on producers is 1+2+4+5+6-(3+4+5+6) = 1+2-3, which is simply the total effect of the supply shift and resulting price change on producers' surplus. The price effect on consumers is 3+4+5, which is part of the amount lost by producers. Since there is no demand shift, the price effect equals the total effect on consumers' surplus. The effect on social surplus is given by the sum of the shift and price effects, which is 1+2+4+5+6-(3+4+5+6)+3+4+5 = 1+2+4+5. This is exactly the area described working directly from the definition of the change in social surplus.

Table 1. Summary of Gains and Losses for Producers and Consumers, from Figure 11

Producers gain (a)	1	2		4	5	6
Producers lose (b)			3	4	5	6
Producers' net gain (c = a - b)	1	2	-3			
Consumers gain (d)			3	4	5	
Total net gain (c + d)	1	2		4	5	

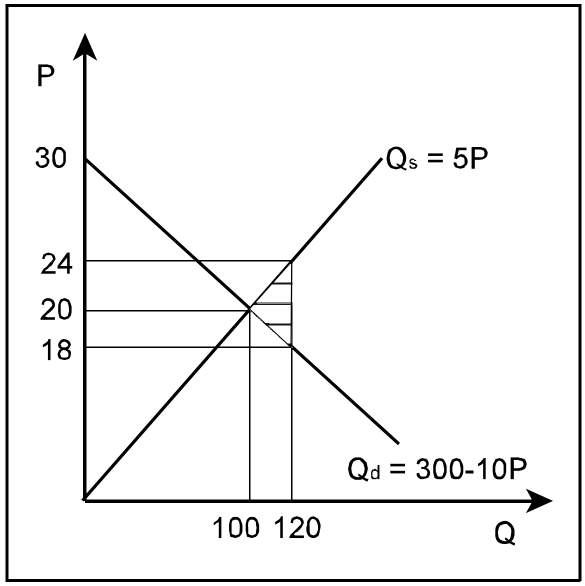
4. Applied Welfare Analysis with Price Distortions

The following two cases investigate the changes in social surplus with no shift in demand or supply.

a. Price support policy

Let us return to the competitive equilibrium for our basic model, in which:
$Q_d = 300 - 10P$ and $Q_s = 5P$. Suppose the government wishes to increase output and farmers' incomes by supporting the output price to a level of P = 24. At this price (paid by government on all units of output), farmers are willing to increase supply from 100 to 120 (Figure 12). This reduces the market price to 18. How does this affect social surplus?

Figure 12. Effect of Price Support



- We know that the social surplus associated with the original equilibrium is ½×30×100, or 1,500.

- The price support policy increases producers' surplus by the amount: (24 - 20)×100 + ½×(24 - 20)×(120 - 100) = 400 + 40 = **440**

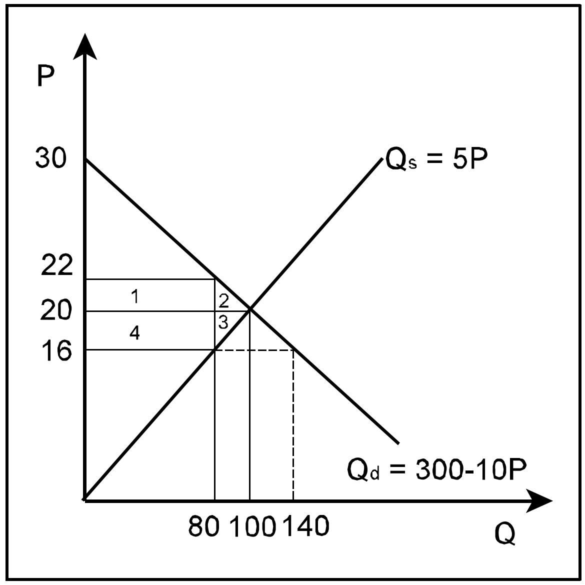
- The price support policy increases consumers' surplus by the amount: (20 - 18)×100 + ½×(20 - 18)×(120 - 100) = 200 + 20 = **220**

- This would seem to indicate that the price support policy increases social surplus by a total of 660. However, to determine the net impact on social surplus, we need to take into account the cost of the price support policy to the government. Since the government pays a price of 24 for all units of output, the total support cost is (24 - 18)×120, or **720**. This exceeds the increase in producers' and consumers' surplus by **60**. Overall, then, the price support policy generates a loss in social surplus. As Gramlich (1990) notes in his Chapter 4, this is true of any policy that distorts the market away from the competitive equilibrium.

- Another way of calculating the loss associated with a distortionary policy such as a price support is to calculate the **deadweight loss**, which is the area over which cost exceeds value. This is represented in Figure 12 by the horizontally barred triangle to the right of the intersection of the supply and demand curves and bounded by the post-support output level of 120. The area of this triangle is ½×(24 - 18)×(120-100), or 60, which is the same as the loss in social surplus calculated in the previous paragraph.

b. Price control (ceiling price) policy

Figure 13. Effect of a Ceiling Price Policy.



Starting from the same model of competitive equilibrium, suppose now that the government wants to gain votes. It does so by lowering food prices to consumers by putting a ceiling price on the product of P = 16. At that price, producers are now willing to supply an amount of only 80 (Figure 13). The restriction in supply drives the market price up to P = 22.[2] Government implements the ceiling price by paying producers the difference between the ceiling price of 16 and the post-policy market price of 22. The effects on consumers' and producers' surplus are as follows:

- The ceiling price policy has both positive and negative effects on producers' surplus. Producers gain surplus on the output of 80 (rectangle 1 in Figure 13), but lose surplus on the amount by which output falls (triangle 3 in Figure 13):
  (22 - 20)×80 - ½×(20 - 16)×(100 - 80) = 160 - 40 = **120**

- The ceiling price policy also has positive and negative effects on consumers' surplus. Consumers gain surplus on the output of 80 (rectangle 4 in Figure 13), but lose surplus on the amount by which output falls (triangle 2):
  (20 - 16)×80 - ½×(22 - 20)×(100 - 80) = 320 - 20 = **300**

- This apparent gain of 420 in social surplus is offset by the cost to government of implementing the ceiling price policy, which is the subsidy payment of (22 - 16)×80 = **480**. Taking the government cost into account, the net change in social surplus is 420 - 480 = **-60**. This is made up of the loss in consumers' and producers' surplus calculated above (20 and 40, respectively).

- Note that at the ceiling price of 16, consumers would like to purchase an amount of 140. The effects of this excess demand are not considered in this example.

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[2]This cannot happen if the ceiling price is enforced (Gramlich, 1990, pp. 64-66).

The following two cases examine surplus changes associated with supply shifts in the presence of policy distortions, first a price support, and second a price ceiling.

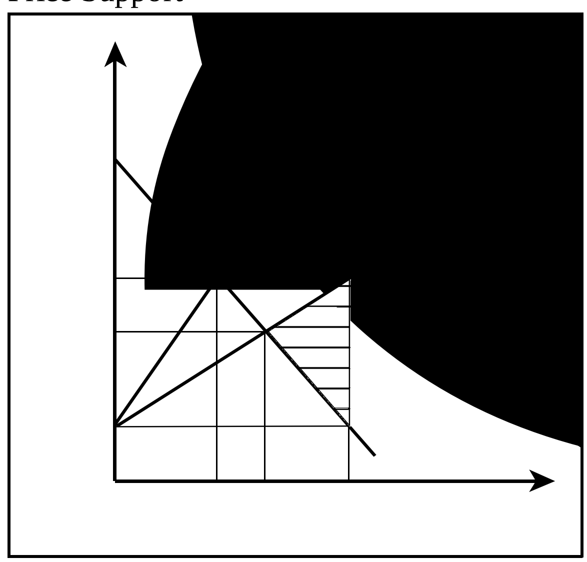
c. Effect of supply shift in the presence of a price support

Let us now consider how the presence of a price support policy alters the net economic impact of a research-induced supply shift. Two somewhat different scenarios can be examined, the first in which the price support policy appears only in the "with-research" scenario, and the second in which both "without-" and "with-research" scenarios include the price support policy. The questions that correspond to these two scenarios are:

1) What is the effect of implementing a price support program given that research has shifted out the supply curve? and,

2) What is the economic impact of the research program given the prior (and continued) existence of the price support?

Figure 14. Pivotal Supply Shift with New Price Support



For the first scenario, suppose that the government is concerned that increased output resulting from adoption of new agricultural technology will lower the market price. The government therefore implements a price support program to protect local producers. Assume that the government pays producers the difference between the support price and the market equilibrium price, leaving the price to consumers unchanged. Figure 14 shows a case where $P_e = 20$ without research, $P_e' = 16.25$ with research, and the government-supported price $P_G = 20$.

To answer question (1), we want to subtract the social surplus with the research but without the price support policy (SS_{P0}) from the social surplus with the research and the price support policy (SS_P), taking into account the economic cost of the price support. With the price support policy, the with-research quantity produced = 90 and the equilibrium price (paid by consumers) = 5.[3]

- $SS_P = CS_P + PS_P = ½×(50 - 5)×90 + ½×(20 - 5)×90 = 2025 + 675 =$ **2700**

- $SS_{P0} = ½×(50 - 5)×67.5 =$ **1518.75**; or

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[3] $Q_s' = (6 \times 22) - 30$. Plugging 90 into the equation for Q_d gives $90 = 100 - 2P$, or $P = 5$.

$CS_{P0} + PS_{P0}$ = ½×(50 - 16.25)×67.5 + ½×(16.25 - 5)×67.5
= 1139.0625 + 379.6875 = **1518.75**

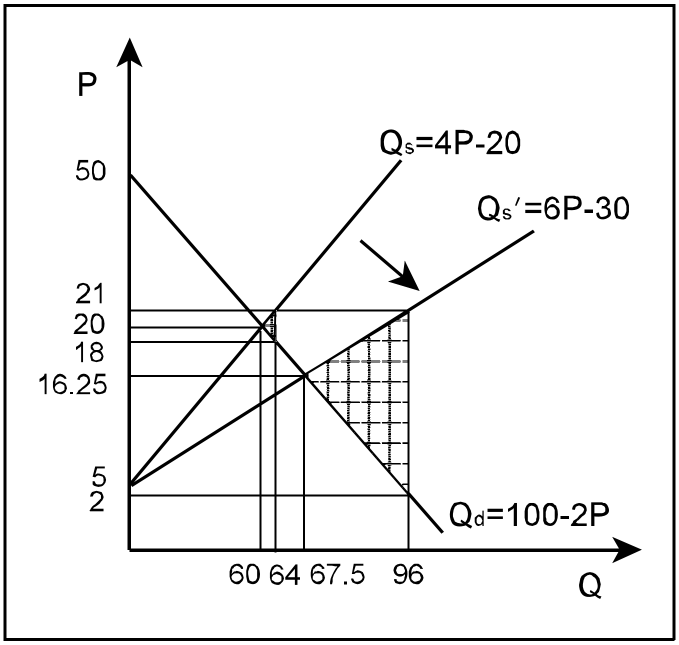
- The cost of the government price support is: (20 - 5)×90 = **1350**

- Therefore the net impact of the price support policy is 2700 - 1518.75 - 1350 = **-168.75**, i.e., a net loss.

- Note that the amount of the net loss is the same as the deadweight loss (DWL) associated with implementing the price support policy. The DWL can be interpreted as the portion of the government cost of the price support policy that is not transferred to either producers or consumers. The DWL is represented in Figure 14 by the horizontally barred triangle, which equals ½×(20 - 5)×(90 - 67.5) = **168.75**.

For the second scenario, assume that the price support policy is incorporated in the base or "without-research" scenario. Let us use the same supply and demand curves, but suppose that the producer support price is 21, slightly higher than the without-research equilibrium price (P_{R0}) of 20 (Figure 15). The output supplied at P_{R0} of 21 is Q_{R0} = 64. The demand price for an output of 64 is 18 ([100 - 64]/2). With the supply shift, the equilibrium price and quantity are 16.25 and 67.5 as before. At the support price of 21, however, quantity supplied is 96 ([6×21] - 30). The demand price for an output of 96 is 2 ([100 - 96]/2).

Figure 15. Pivotal Supply Shift with Price Support Continued



To answer question (2), we want to subtract the social surplus with the price support but in the absence of research (SS_{R0}) from the social surplus with the price support and with research (SS_R).

- CS_R = ½×(50 - 2)×96 = 2304
  PS_R = ½×(21 - 5)×96 = 768
  SS_R = 2304 + 768 = **3072**

- The cost of the government price support is (21 - 2)×96 = 1824. The net gain is therefore 3072 - 1824 = **1248.** Note that the DWL in this scenario (large hatched triangle in Figure 15) is ½×(21-2)(96-67.5) = **270.75.**

With the price support but in the absence of research:

- CS_{R0} = ½×(50-18)×64 = 1024
  PS_{R0} = ½×(21 - 5)×64 = 512
  SS_{R0} = 1024 + 512 = **1536**

- The cost of the government price support is (21 - 18)×64 = 192. The net gain is therefore 1536 - 192 = **1344.** Note that the DWL in this scenario (small hatched triangle in Figure 15) is ½×(21-18)(64-60) = **6.**

- The incremental net gain resulting from the research-induced supply shift, given that the price support policy appears in both without- and with-research scenarios, is 1248 - 1344 = **-96**, i.e., a net loss. This net loss results from the fact that the supply shift increases the economic loss associated with the government's price support program by expanding the quantity of output on which the price support is paid. (See Oehmke, 1988, for more detailed discussion.)

- The net loss of -96 can be decomposed into the change in social surplus with research but without the price support policy, and the change in deadweight loss with the price support in place:

  1) As can be seen in Figure 14, the change in social surplus is:

     - the with-research social surplus: ½×(50 - 5)×67.5 = 1518.75, minus
     - the without-research social surplus: ½×(50 - 5)×60 = 1350, giving
     - the change in social surplus: 1518.75 - 1350 = **168.75**

  2) Based on the above calculations, and as shown in Figure 15, the change in deadweight loss is the with-research DWL (270.75) minus the without-research DWL (6) = **264.75**.

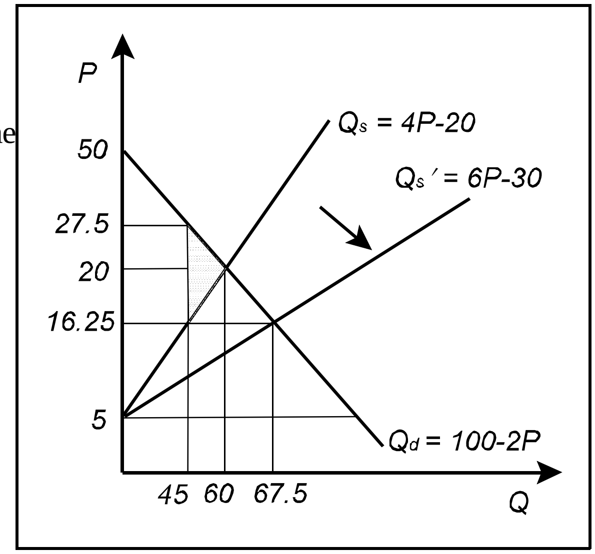
- The difference between the change in social surplus, which is an economic gain, and the change in DWL, which is an economic loss, is 168.75 - 264.75 = **-96**, which is the net loss calculated above.

d. Supply shift in the presence of a price ceiling policy

A net loss will always result from a distortionary policy providing that the supply and demand curves reflect private costs and values that are the same as social costs and values. The case examined in (c) above shows that a research-induced supply shift may have overall negative effects on social surplus if the expansion of output leads to a large increase in the cost of implementing the policy. However, a supply shift in the presence of some types of distortionary policies may have an offsetting effect that is positive.

As an example, let us look at the case of a country with a closed economy and a policy of keeping the price of the main staple food grain below the equilibrium price to make food affordable for urban consumers (Figure 16). Assume that producers are paid the controlled price of 16.25. The price control policy entails a deadweight loss (DWL) of 84.375 (the shaded triangle in Figure 16). The social surplus given the initial supply curve is:

Figure 16. Pivotal Supply Shift with Price Control



- CS = ½×(50 - 27.5)× 45 + (27.5 - 16.25)×45 = 1012.5
  PS = ½×(16.25 - 5)×45 = 253.125
  SS = 1012.5 + 253.125 = **1265.625**

- This is the same amount as the social surplus in the absence of the price control, less the DWL: 1350 - 84.375 = **1265.625.**

- Now a research-induced shift in the supply curve to Q_s' will not only generate an economic gain of 168.75 (i.e., 1518.75 - 1350), but it will also eliminate the DWL of 84.375, giving a total benefit to society of 168.75 + 84.375 = **253.125**, which is the amount of the gain in producers' surplus indicated above.

5. Applications to Evaluation of Agricultural Research Impacts

a. Formulae for approximate calculations

Alston, Norton and Pardey (1995, pp. 209-211) give a number of formulae for the welfare effects of different types of supply and demand shifts. In our analysis of agricultural research, we will be concerned primarily with analysis of supply shifts. The most important formulae are:[4]

Parallel Shift	*Pivotal Shift*
$\Delta SS = P_e Q_e K(1 + 0.5Z\eta)$	$\Delta SS = 0.5KP_e Q_e(1 + Z\eta)$
$\Delta CS = P_e Q_e Z(1 + 0.5Z\eta)$	$\Delta CS = P_e Q_e Z(1 + 0.5Z\eta)$
$\Delta PS = P_e Q_e (K - Z)(1 + 0.5Z\eta)$	$\Delta PS = \Delta SS - \Delta CS$

[4]Note that a parallel shift implies a constant absolute reduction in supply cost; a pivotal shift implies a cost reduction that is proportional to the level of output.

Numerical Example (Pivotal Shift) (see also Figure 10): $Q_s = 5P$, $Q_d = 300\text{-}10P$, $Q_s' = 10P$. Thus, $P_e = 20$, $Q_e = 100$.

- ξ is the supply elasticity—the percent change in quantity supplied in response to a one percent increase in price.[5] Calculate ξ at the initial equilibrium. If price increases 1% to 20.2, $Q_s(20.2) = 5\times20.2 = 101$, a one percent increase, so $\xi = 1.0$.

- η is the absolute value of the elasticity of demand—the elasticity is the percent change in quantity demanded in response to a one percent increase in price. Calculate η at the initial equilibrium. $Q_d(20.2) = 300\text{-}10\times20.2 = 98$, a two percent decrease, so $\eta = |\text{-}2.0| = 2.0$.

- K is the vertical shift in the supply function expressed as a proportion of the initial price. After the supply shift, the height of the new supply curve at the initial equilibrium quantity, $Q_e = 100$, is $100 = Q_s' = 10P$, or $P = 10$. The price change as a proportion of the initial equilibrium price is $(P_e\text{-}10)/P_e$, or $(20\text{-}10)/20$, so $K = ½$.

- $Z = K\xi/(\xi+\eta) = ½\times1.0/(1.0+2.0) = 1/6$.

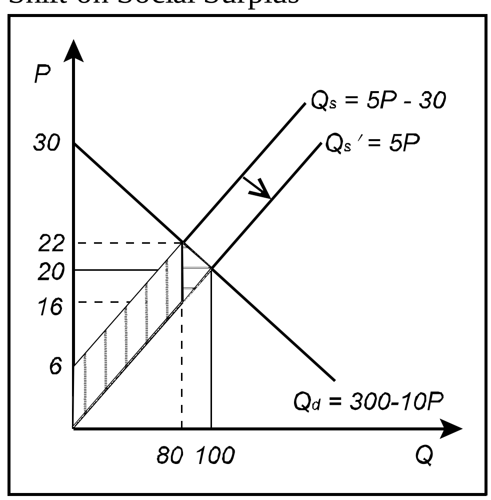
- Now we can apply the formula. The change in social surplus is $½\times½\times20\times100\times(1+1/6\times2.0) = 500\times4/3 =$ **667**. The change in consumers' surplus is $20\times100\times1/6\times(1+½\times1/6\times2.0) =$ **389**. The change in producers' surplus is 667-389 = **278**. Note that the change in social surplus calculated with this approximate formula (667) is substantially less than the 750 calculated in section 3.d, and illustrated in Figure 10.

Numerical Example (Parallel Shift) (see also Figure 17): $Q_s = 5P - 30$, $Q_d = 300\text{-}10P$, $Q_s' = 5P$. Thus, $P_e = 22$, $Q_e = 80$, $P_e' = 20$, and $Q_e' = 100$.

- Change in social surplus: $SS' - SS = ½\times30\times100 - ½\times(30 - 6)\times80 = 1500 - 960 =$ **540**
  Or, calculating the areas of the barred parallelogram + triangle:
  $6\times80 + ½\times6\times(100 - 80) = 480 + 60 =$ **540**

- To apply the Alston, Norton, and Pardey formula for a parallel shift, first calculate ξ at the initial equilibrium. If price increases 1% to 22.22, $Q_s(22.22) = 5\times22.22 - 30 = 81.1$, an increase of 1.375 percent. $\xi = 1.375$.

Figure 17. Effect of Parallel Supply Shift on Social Surplus



[5] Estimating elasticities is typically an econometric exercise that is beyond the scope of a course in benefit-cost analysis. However, compendia of previously estimated elasticities are readily available. One source is Tsakok (1990), Appendix D.

Then calculate η at the initial equilibrium: $Q_d(22.22) = 300-10\times22.22 = 77.8$, a decrease of 2.75 percent, so $\eta = |-2.75| = 2.75$.

- K, the vertical shift in the supply curve, is (22-16)/22 = 0.2727

- Therefore Z = (0.2727 × 1.375) / (1.375 + 2.75) = 0.375 / 4.125 = 0.0909

- The change in social surplus is therefore: 22 × 80 × .2727 × (1 + (0.5 × .0909 × 2.75) = 480 × (1.125) = **540**, exactly the same as calculated directly.

Elasticities

The elasticities of supply and demand affect the changes in consumers' and producers' surplus. For producers, research has two effects:

1) It reduces unit production costs (shifting the supply curve downward), which is good.

2) Unless demand is perfectly elastic, it also reduces the output price, which reduces producer surplus and is therefore not good.

So, the net gain for producers depends on the magnitude of the loss of producers' surplus due to the price decline, relative to the production cost reduction. This is determined by the elasticity of demand:

1) If demand is elastic (relatively flat), the net gain to producers is positive—total revenue rises because the increased quantity demanded outweighs the lower price. This would be especially the case for export crops, whose demand is often perfectly elastic (Masters et al., 1996).

2) If demand is inelastic (relatively steep), the net gain is negative, because the quantity demanded does not increase much despite the fall in price.

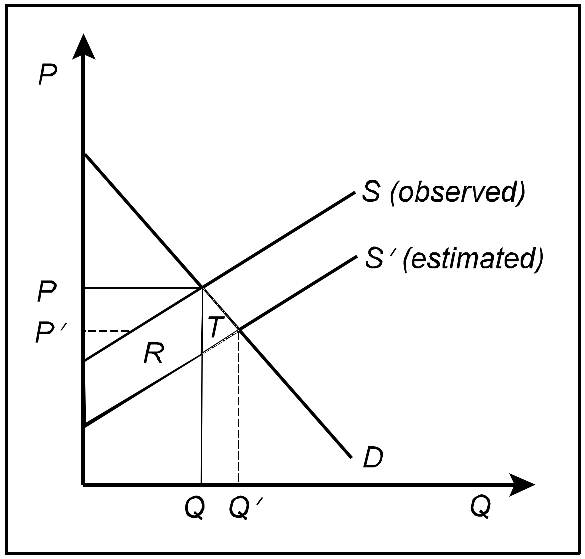
Consumers never lose as a result of research. At worst, when demand is perfectly elastic (no price decline), their gain in consumers' surplus is zero. Whenever demand is less than perfectly elastic, their gain in CS is positive. This would be especially the case for research on staple foods, whose demand is relatively inelastic (Masters et al., 1996).

In early studies of agricultural research impact, e.g., Akino and Hayami (1975), the magnitude of overall social surplus was not sensitive to the values of supply and demand elasticities. More recent literature, including Alston, Norton, and Pardey (1995) and Masters et al. (1996), has conveyed the same message. However, Oehmke and Crawford (2002) showed that the formulae introduced in recent studies, while representing methodological improvements, have also made the estimate of overall social surplus quite sensitive to the value taken for the supply elasticity.

Masters et al. (1996) present formulae and procedures that are somewhat different from, although based closely on, those in Alston, Norton, and Pardey (1995). Masters distinguishes *ex ante* from *ex post* impact analysis:

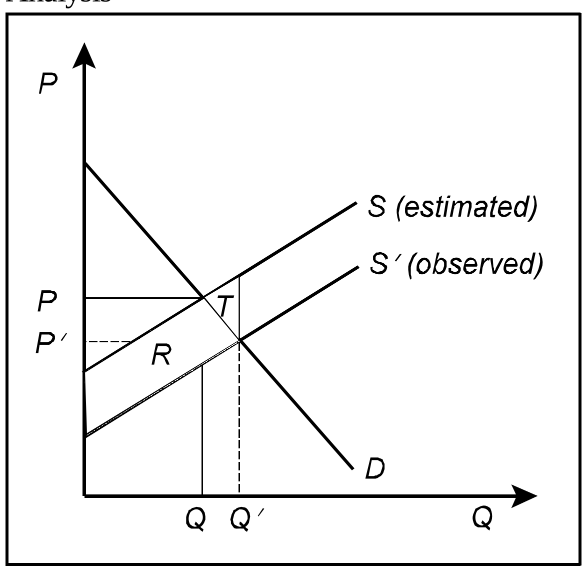
1) *Ex ante* impact analysis is conducted before the research is carried out. What you observe is without-research Q and P, based on S, and you have to estimate with-research Q′ and P′ based on S′. Masters splits the research gain into area R (value of cost reduction on the without-research production) and area T (value on increased production), shown in Figure 18 for a parallel supply curve shift (which reflects an equal cost reduction for all levels of production). The total research gain is represented by areas R + T.

Figure 18. *Ex Ante* Research Impact Analysis



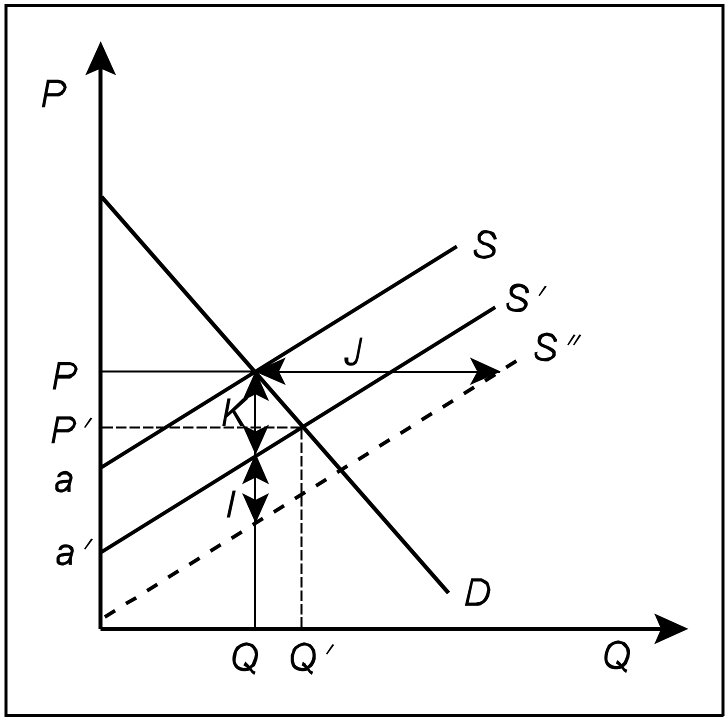
2) *Ex post* impact analysis is conducted after the research has occurred, to find out what impact it had. Here what you observe is with-research Q′ and P′, based on S′, and you have to estimate without-research Q and P. In this case, the parallelogram R (bounded on the right by Q′) includes triangle T, so that in calculating the research gain you <u>subtract</u> T from R (Figure 19).

Figure 19. *Ex Post* Research Impact Analysis



The major issue in this approach is estimating the height of R, i.e., the magnitude of the supply shift. For purposes of estimating the supply shift from empirical data, Masters (p. 12) identifies the following components of the research-induced supply shift (see Figure 20):

Figure 20. Estimating Supply Shifts Using Observed Data



1) A <u>horizontal</u> shift, J (from S to S″), that reflects an increase in quantity produced per unit of input, measured by the yield change times the area cultivated using the new technology.

2) A <u>vertical</u> shift, I (from S″ to S′), that represents the cost per unit of adopting the new technology, measured by dividing adoption costs per ha by the average yield for the total area cultivated (old technology plus new technology). E.g., \$50/ha higher costs divided by an average yield of 500 kg/ha gives I = 50/500 = \$0.10 per kg. Note that if no cost is required for adoption of the new technology, then S″ would be the with-research supply curve.

3) A <u>vertical distance</u>, K, that represents the combination of these two effects, giving the net shift in supply (from S to S′ in Figure 20). K is referred to as the "shift parameter."

4) So, assuming an *ex ante* analysis, the total gain is a parallelogram analogous to R in Figure 18, whose length is Q and height is K, and a triangle analogous to T in Figure 18, whose base is K and height is Q′ - Q, the increase in quantity due to research.

Table 2 summarizes the key formulae and calculation procedures given by Masters et al. (1996) for estimating the net social gain from research.

Table 2. Key Formulae and Calculation Procedures for Estimating the Net Social Gain from Research

Steps	**Definition**	**Formula**	**Data and Typical Units**
1. Computing j	Change in production due to new technology, as a proportion of total production	$j = \frac{(\Delta Y \times t)}{Y}$	•ΔY: Yield difference between new and old technology (kg/ha) •Y: Average yield, i.e., total production divided by total acreage (kg/ha) •t: Adoption rate, i.e., area under new technology divided by total area (ha)
2. Computing c	Adoption costs of the new technology, as a proportion of the product price	$c = \frac{\Delta C \times t}{Y \times P}$	•ΔC: Input cost difference between new and old technology ($/ha) •P: Average price paid to producers in real terms ($/kg)
3. Computing k	Net change in production costs, as a proportion of the product price	$k = [\frac{j}{\epsilon}] - c$	•ϵ: Elasticity of supply, drawn from economists' estimates
4. Computing ΔQ	Change in the equilibrium quantity produced due to the new technology	$\Delta Q = \frac{[Q \times \epsilon \times e \times k]}{[\epsilon + e]}$	•Q: Total production (kg). Note: Q and ΔQ have the same units •e: Elasticity of demand, drawn from economists' estimates
5. Computing social gains	Economic benefits from the adoption of research results	$SG = [k \times P \times Q] \pm \frac{1}{2}[k \times P \times \Delta Q]$	•Subtract the second term when data are observed after adoption (*ex post* study); add it if adoption has not yet occurred (*ex ante* study)
6. Computing net social gains	Net economic benefits, after subtracting the costs of research and extension	NG = SG - R - E	•R: Total cost of research ($) •E: Total cost of extension ($)

Source: Adapted with permission and minor revisions from Masters et al., 1996, pp. 27-28. They note (p. 28) that " . . . the formulas presented here are strictly correct only in the case of linear functions with a parallel shift of the supply curve. But they are not very different from the formulas used in other cases."

Let us now apply the Masters et al. formulae to the numerical example of a parallel shift in supply presented above and represented in Figure 17. In this example, $Q_s = 5P - 30$, $Q_d = 300 - 10P$, $Q_s' = 5P$. Thus, $P_e = 22$, $Q_e = 80$, $P_e' = 20$, and $Q_e' = 100$.

Assuming an *ex ante* analysis, the formula for net social gain is:

- $SG = [k \times P \times Q] + ½ [k \times P \times \Delta Q]$, where P = 22 and Q = 80 at initial equilibrium
- $k = [j/\epsilon] - c$, where j is the horizontal supply shift, or proportional yield gain
    - since Q_s' at P=22 is 110, the horizontal supply shift is 110 - 80 = 30. As a proportion of Q_s, j is therefore 30/80 = 0.375
    - ϵ was calculated above as 1.375; assume c = 0; then,
    - k = 0.375/1.375 = **0.2727**
- $\Delta Q = [Q \times \epsilon \times e \times k] / [\epsilon + e]$; 80 × 1.375 × 2.75 × 0.2727] / [1.375 + 2.75]
    = 82.49 / 4.125 = **20**
- Then SG = 0.2727 × 22 × 80 + ½ [0.2727 × 22 × 20] = 480 + 60 = **540**, the same number calculated directly and by using the Alston, Norton, Pardey approximation formula.

b. Attribution of benefits due to supply shifts

The issue of attribution of benefits arises because successful research and technology development often takes place at the same time as success in other development activities, such as infrastructure improvement, etc. It is therefore often difficult to attribute some or all of the benefit to the technology activity. This raises two issues: have the benefits of research been calculated correctly in the benefit-cost analysis, and are the lessons learned and implications for further investment appropriate?

To illustrate the issue, consider two hypothetical technical innovations in a semi-arid area: an improved millet variety and innovative water harvesting techniques (Table 3). With just water harvesting, yield increases from 200 kg/ha to 600 kg/ha; with just the improved variety, yield increases from 200 kg/ha to 500 kg/ha; but with both, the yield increases to 1,500 kg/ha. Thus, the impact of the varietal improvement could be calculated either as 300 kg/ha, the improvement in the absence of water harvesting, or as 900 kg/ha, the improvement if the water harvesting is already in place.

Table 3. Hypothetical Example of Attribution Issue.

Hypothetical Yields	Traditional Variety	Improved Variety
No Water Harvesting	200 kg/ha	500 kg/ha
Water Harvesting	600 kg/ha	1,500 kg/ha

The second issue, of lessons learned, is more important. Suppose the sequencing is water harvesting then variety, so that the attribution of yield increase is 400 kg/ha to the former and 900 kg/ha to the latter. This tends to obscure the real lesson learned: the yield increase from the complementarity between the two innovations is 2-3 times the yield increase from either innovation in isolation. The implication is that for similar areas, a multi-faceted research approach may generate the biggest impact. There is no "right answer" or "correct method" for attribution of benefits to individual effects. The critical issue in attribution is that the BCA not focus on a single impact measure, but draw forth the lessons about the best portfolio of technology development and other investments that can achieve sustainable increases in productivity.

c. Illustrative exercise: Zambian maize research

Background information[6]

The Northern Province of Zambia is a high-rainfall area (1000-1500mm) with a growing season of 120-150 days. It is relatively densely wooded, and even with a population of 900,000 is the least populated part of the country. Soils are leached, weathered, acidic, and high in exchangeable aluminum and manganese, both of which are toxic to most crops. Most farmers are smallholders, producing finger millet, cassava and maize; maize is the preferred staple. Increased land clearing and intensification of maize production has raised questions about soil erosion and sustainability. Soil impacts to date have been relatively minor because farmers switch to a new area every 3-5 years; continuous monocropping of maize without liming and fertilization would lead to declining soil productivity.

The Northern Province is remote from the major urban centers in Zambia and the transportation lines. As a result, both input and output markets function erratically. Historically, the government subsidized both input delivery and output purchase; during these periods, the farmers were able to sell all their maize produce at a government-established price. However, even with subsidized delivery, only 20% of fertilizer actually shipped to the Northern Province was available for planting, in most years. Yet over 90% of the farmers apply fertilizer to maize.

Maize technology development and transfer has focused primarily on varietal development and transfer, with several results. First, the Zambian seed stocks of the SR52 hybrid released in 1960 had become impure; repurified SR52 has a 14.3% yield advantage over local maize varieties in the absence of fertilizer. Second, importation of other Zimbabwean varieties developed for low-input conditions improved yields over local varieties by 157%. Third, development of hybrids by the Zambian research institute increased yields over local varieties by 186% in the absence of fertilizer. For the purposes of this exercise, we will focus on Zambian hybrids and government policy.

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[6]Adapted from Howard, Chitalu, and Kalonge (1993a, b).

Economic information

Assume that the Northern Province is autarkic, with constant elasticity supply curves of the form $Q_{s,i} = a_i P^{\epsilon}$. The subscript i can be used to denote with- and without-project scenarios. Assume that the elasticity of supply is $\epsilon = 0.65$. Without the Zambian hybrids or the market interventions, the quantity supplied is 110,000t and the market price is 1,400ZK/t (based on historical data, price adjusted for inflation). The improved Zambian varieties are grown on 35% of maize area.

The government imposes a joint fertilizer distribution and price guarantee policy. Applying the recommended dose of fertilizer increases the yield of the local variety by 72%. The yield advantage of Zambian improved over local varieties is 65% when fertilizer is applied. Assume that the adoption of improved varieties does not increase the costs of production, but that use of fertilizer (even at subsidized prices) increases maize production costs by 25%. 100% of the improved variety area is fertilized, but only 50% of the local varieties are fertilized.

Assume that the demand curve is also constant elasticity, with an absolute value of price elasticity of 0.1: $Q_d = 900{,}000 \times 0.25 \times P^{-0.1}$. Assume the demand curve does not shift over time.

Exercise tasks

1) Suppose you are the economists for the Zambian research system, and you are given the task of calculating the benefits. Do so.

2) How would you react to the results of these calculations if you were: a plant breeder? An agronomist? The Director General of the National Agricultural Research Institute? The president of the Zambian farmers organization? The president of the fertilizer parastatal? The Minister of Agriculture? The IMF representative to Zambia? The president of a new environmental group, Worldwide Forestry Conservancy?

Hints on Task 1:

1) Calculate the unknown parameters in the supply and demand curves.

2) Assume that the yield of local varieties without fertilizer is 1 t/ha (you can always scale this later). Construct a 2x2 table of yields by variety and fertilizer use.

3) Based on this table, think about how you might want to represent supply shifts.

4) Pick a benefits estimation approach—exact calculation of social surplus; a formula from Alston, Norton and Pardey; a measure of increased revenue to producers, etc.

5) If your approach requires it, calculate the magnitude of the supply shift.

6) Finish the approach to obtain the benefit.

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