## PRICE DYNAMICS WITH SHOCKS IN SUPPLY AND DEMAND


#### Abstract

An example of optimizing the dynamics of prices in the meat products market with a jump in supply and demand, when the reaction to a change in demand is limited by objective features of production technology, is considered.


Keywords: Surges in demand, price dynamics, minimization of losses.

Target setting. When the market is in equilibrium, the price that gives the maximum profit to manufacturers [5] is set, regardless of whether the market is monopolistic or competitive. Small changes in supply or demand are eliminated by price fluctuations. However, with significant jumps in demand and when there is no possibility to change the level of supply immediately, a non-optimal price is set and kept for a long time, when the manufacturer objectively does not reach the desired profit. Our objective is to use the example to show how the price should change over time to minimize profit losses.

Analysis of publications. To start with the highly controversial observation of laureate Jean Tirole that: "... another common theme in the literature ... is the asymmetric price response to upward and shocks... Because of this possibility of quantity adjustment for low demand, but not to high demand, the ... price ... tends to react more to upward shocks in demand than to downward shocks" $[2,113]$. What is not clear here is what is meant by the degree of responsiveness of... prices. After all, prices can be changed almost instantaneously in times and in any direction. Another observation by Jean: "Most of the literature... considers linear demand function" $[2,606]$. The grounds for this "preference" are not given, but in [5] it is shown that the linear demand function is characteristic of durable goods, which have a rigidly fixed income from their consumption over their lifetime, while, for example, the exponential one is characteristic of one-time consumption
goods, which already have a fixed profit from their consumption (regardless of the price).

And because of this kind of carelessness in the use of demand functions, as a consequence, we read: "In a monopolized industry, the demand function has a constant elasticity: $q=D(p)=p^{\varepsilon}$ where $\varepsilon>1$ is the elasticity of demand" $[2,101]$ (here $q$ is demand, $p$ is price). If we "believe" this formula, then there are goods in the world for which demand $q$ increases ... as the price $p$ grows.

Or this statement: "For instance, a firm's low profit may be due to a decrease in demand or an increase in costs rather than to managerial slack" [ 2,65 ]. There are no such "managers" in typical firms, while decreasing profits (in the sense that profits are objectively lower than its possible maximum) can also occur when demand increases (when there is no opportunity to increase production). Yet, the managers of Jean's firms behave strangely because: "Temptation to undercut is higher, when demand is high" $[2,390]$. Have you ever seen a firm lowering its price because of... increased demand? But Jean is relentless: "When demand is high, the temptation to undercut is important... [and although it is V. Sh.] will entail a loss of profit, but its magnitude will be neither the highest nor the lowest" $[2,390]$. Jean's firm managers are tempted ... to lose profits. And wouldn't it be interesting to know which loss is the lowest? And the highest? And then there are the oddities in the behaviour of the two firms: "firm 2 requires to lower its price, which increases the demand
of firm 1" $[2,573]$. There were two identical firms in the market. One lowered its price in the hope of raising its demand, but it turned out to... vice versa, demand increased at... its competitor. The reverse, where firm 2 raises the price, Jean ignored it. Another problem with Jean's firms vision, for: "Each firm sees only the realization of its demand, so its rival can secretly lower the price" $[2,577]$. How can the price be secretly lowered if it has to be known to all buyers in the market? But let each firm see nothing but its own demand. Then how to understand this phrase where: "firm 2's demand depends on two unobservable variables: demand uncertainty and the price of firm 1" [2, 574]. If we only observe demand, then the demand uncertainty is also observable, and of the unobservable variables there remains one - price, which we have yet to learn not to see. And yet, in Jean's book we read: "The theory considered in this section... assumes random and unobservable demand" $[2,429]$, where demand is already unobservable. By the way, how do we know that demand is random if it is unobservable?

And Jean's "observation": "industry demand is subject to periodic and unobserved random shocks" [ 2,387 ]. If a shock is periodic, it cannot be random, but if it is unobservable, then there is the problem of who and how can it be observable? And how: "Firms... to set a monopoly price... until the next deviation or until a sharp fall in demand" [2, 394], if demand is unobservable? Elsewhere it is already clarified that: "firms assign monopoly prices until their profits are reduced by a demand shock" [2, 394]. Let the firm's profits decrease (due to an unobserved demand shock) by $\mathbf{0 . 0 6 \%}$. What it should do next, and whether such a decrease is worth taking into account,- is not clear. Another similar thing: "The occasional price war is nonrandom, it is not caused by a decrease in price but rather by an unobservable sharp fall in demand" $[2,394]$. If demand is unobservable, who will declare war on whom first?

And a number of bloopers on the subject. Jean is able to make: "a claim against the party who performs
the unobservable action" [2,57]. Which court accepts such claims is not specified. Jean states: "An effort, if it is unobservable, must be induced by means of incentives" $[2,60]$. Well, I have stimulated the plumber (you know with what), and the tap keeps leaking. But his justification is in this phrase of Jean ... From the laureate: "High demand today generates high demand in the future" $[2,112]$. Where does the crisis of overproduction come from, can demand go down in such a scenario, how far in time this "bright" future extends, Jean omits. The problem for mathematicians is given: "in the case of linear demand $D(p, d)=$ $=d-p$, where the first derivative equal to 1 , and the next two derivatives equal $1 / 2 \ldots$.." 2,296$]$. Find: by which variable $p$ or $d$ has Jean differentiated, and what would then be the third derivative? Would Jean be able to pass math analysis in the USSR and become a Nobel Prize winner if his derivative of 1 equals $1 / 2$, and the derivative of $1 / 2$ is also $\ldots 1 / 2$ ?

Or: "episodes of price declines must be attributed to other, more innocent factors, such as fluctuations in demand" [2, 589]. So, the demand for a commodity fluctuates, and for this reason prices only occasionally... decrease. And the necessity of attributing to others ... innocents is typical for the security apparatus known to us when they draw up quarterly reports "to the top".

And Jean's definition of the term: "Two goods are complementary for the consumer if a reduction in the price of one good makes the other good more attractive to the consumer" $[2,323]$. For me, tea and coffee sort of complement each other. Coffee prices have plummeted, and I am being drawn to tea. And then there is the paradox of demand: "the net surplus of the consumer decreases with the average retail price and increases with the dispersion of demand" $[2,298]$. The net surplus is the buyer's profit from the exploitation of the thing. It turns out that the lower the price of a good, the lower the buyer's profit from its consumption. And if the demand for the good this year "disperses" a lot, then your profit from the exploitation of the good (bought 9 years ago) undoubtedly increases.

But here is his valid point: "the market price cannot match unobservable quality" $[2,163]$. Indeed, if nothing is known about the quality of goods, and the price is on the price tag, then it is difficult to establish the correspondence of this price to something which is not known and which nobody sees.

Prizewinner Richard Thaler is not far behind. Here's how he tells his students how to solve such problems: "There is a fixed supply in the market... and demand has suddenly risen. What will happen to the price?" The correct answer in the exam is that the price will rise so much that everyone who is willing to pay the new price will be able to buy [3, 140]. But exactly how much the price should increase is impossible to understand. There is a rush for the goods, the demand has increased. You, as a seller, tripled the price, but the goods were sold in $\mathbf{5}$ minutes. So you miscalculated by tripling the price, you should have increased it more. Same thing, and you raised the price by $9.9 \%$. Buyers left without buying anything. So how do you answer the test correctly so that without knowing the number of people who are willing or able to pay the new price, you don't miss the mark? Another "tip": "In a situation where demand is skyrocketing, the salesman has to weigh everything before deciding between short-term profits and the risk of long-term losses from customer loyalty, which are difficult to measure" [3, 147]. What the seller needs to weigh, where to find out the duration of the shortterm profit, how to measure customer loyalty and why this measurement is difficult - all questions to Richard. And here is his: "The conclusion I draw... a temporary surge in demand ... is a very bad time to be greedy" $[3,148]$. Go ahead, be generous and lower the price... How to determine that the surge in demand will be temporary - is not specified by Richard. And decipher this phrase of Richard's at your leisure: "No one ever asks why prices are so low in the season when prices are at their highest" $[3,150]$, for there are no such "inferences" in textbooks on the logic of analysis. His other piece of advice: "It is incredibly important for business in any field, no matter how
high the demand, not to charge the customer more than a good product is worth ...-even if the customer himself is willing to pay more" $[3,151]$. And the fact that such a "policy" will create a chronic shortage is not his problem.

Paul Samuelson's advice is no less "wise": "a change in supply, for instance as a result of an unexpectedly poor harvest, is likely to raise the price" $[1,5]$. It would be interesting to know, at what probability would the price decrease with a bad harvest? In the same place and on the same subject: "Every child knows that an increase in supply... because of a bountiful harvest... will in all probability cause a fall in prices" $[1,5]$. And at what probability it is likely to be the other way round - Paul does not elaborate. And his observation: "the total revenue of all farmers as a whole was less with a good harvest than with a bad one" $[1,5]$. Long live bad harvests! Or, there is a lot of talk, even among the laureates, about demand surges and producer shocks, but it is not clear what to do about them or how to respond "correctly" to shocks.

Therefore, it is difficult to disagree with the opinion of V. Leontiev: "I tried to eliminate the shortcomings of classical and neoclassical analysis of supply and demand. I always thought it was terribly haphazard" [4]. And Friedman: "I am convinced that short-term fluctuations in the economy are simply an accumulation of random shocks. I do not believe in the existence of a business cycle. I believe that there are fluctuations and reaction mechanisms to them". [4], but "I am sure", "I do not believe" and "I believe" reek of subjectivism and should have no place in scientific research and evidence. How can one not believe in the existence of the business cycle, when in [4] we read directly: "The writings of Cass ... laid the foundation for the theory of real economic cycles". Or cycles are real, but one can... not to believe in them. But Cass noted that: "The trouble is that the theory of the real economic cycle has today become almost a religion", and in religion the words believe-don't-believe are acceptable.

Statement of the basic material. The peculiarity of the meat market is that it cannot provide the
optimal price in terms of profit with a sudden jump in demand. True, the market was at an optimal price, but demand increased. If we continue trading at this price, when the demand grows, the number of herd will decrease and even disappear, which is unreasonable. If we set the price higher than optimal to support the same demand and herd, the market will be chronically lack of profit, which is unacceptable. Hence, it is necessary to change the price in such a way as to enable both to increase the herd to the new level of demand and to minimize the losses of the "transition process". Indeed, if the price is raised too much, the demand will fall to zero, so will the profit, but the herd will reach the desired level as quickly as possible. The losses from "not selling" are clear. If you only raise the price slightly the herd will grow slowly and the profit will be lower than optimal in the long run and this is also a loss. Another scenario. If there is a sudden decrease of the population (epidemics), you also have to regulate the price of meat to raise the herd to an optimal market situation with minimal losses in profits. Our task is to find the dependence of meat price on time to minimize losses during the "transition period" of herd growth (to its optimum level). A peculiarity of the model is to consider, within the framework of their interaction, the production of the commodity and its price. In some approximation, the model below is applicable to markets where, for example, when demand increases, prices need to be raised to raise funds for expansion of production, or to markets where attracting investment is for some reason impossible. These are, in particular, all kinds of small businesses for which the demand suddenly changes ... Let us introduce the following notations for the parameters of this market:
$M(t)$ - is the mass of the entire live herd of cattle [ton] at time $t$;
$M_{0}$ - is the same mass of the flock at the initial time $t=0$;
$x(t)$ - is the current price of some average meat product [\$/ton];
$x_{0}$-is the optimal price for the same average meat product [\$/ton], which gives the producer the maximum profit;
$N(t)$ - is the maximum possible demand for meat products [ton/day], which is possible with $x=0$ free distribution of meat products in the market;
$N_{0}$ - is the maximum possible demand at the initial time $t=0$;
$a$ - is the profit from the consumption of the "average" meat product [\$/ton];
$\lambda$ - is some "average" herd weight gain rate [1/ day] (e.g., if a $\mathbf{3 0 0} \mathbf{~ k g}$ steer gains $\mathbf{3} \mathbf{~ k g}$ of weight gain per day, then $\lambda=\frac{3}{300}=0.01$ );
$\eta$-is the unit cost of maintaining the whole herd [\$/(day •ton)];
$s$-own cost of commodity production from raw materials [\$/ton].

Since meat is a single-use commodity, the meat market has an exponential dependence of demand on price [5], $n=N \cdot \operatorname{Exp}\left(-\frac{x}{\alpha}\right)$, and therefore, the equation for the herd mass dynamics is (here $M^{\prime}=\frac{\partial M(t)}{\partial t}$ :

$$
\begin{equation*}
M^{\prime}=\lambda \cdot M(t)-N(t) \cdot \operatorname{Exp}\left[-\frac{x(t)}{\alpha}\right] \tag{1}
\end{equation*}
$$

where: $M^{\prime}$ is the mass growth rate of the live herd; $\lambda \cdot M$ is the rate of natural mass gain; $N \cdot \operatorname{Exp}\left(-\frac{x}{\alpha}\right)$, is the "mass loss" rate due to the fact of demand for meat products. When $M^{\prime}=0$ we have an equilibrium point where all the mass growth goes to the market. The herd mass is stable $M=\left(\frac{N}{\lambda}\right) \cdot \operatorname{Exp}\left(-\frac{x}{\alpha}\right)$, but this equilibrium point is unstable with respect to demand at a constant price. Indeed, as soon as demand falls, $M^{\prime}>0$, and the herd mass increases "indefinitely", and as demand rises, $M^{\prime}<0$, and the herd mass eventually evaporates. But fluctuating prices keep supply and demand in equilibrium. The solution to equation (1) of the mass dynamics is:
$M(t)=\operatorname{Exp}(\lambda \cdot t) \cdot\left\{M_{0}-\int N(\tau) \cdot \operatorname{Exp}\left[-\frac{x(\tau)}{\alpha}-\lambda \cdot \tau\right] \cdot d \tau\right\},(2)$
where integration is carried out on [ $0 \ldots \mathrm{t}$ ]. Here: $N(\tau)$ is the dynamics of maximum demand as a function of time; $x(\tau)$ is the price dynamics to be determined.

It should be noted that the dynamics of demand as a function of time $N(t)$ is not a smooth continuous function, but can have finite jumps, for example, when demand jumps by times, or falls (and also by times). Here is what V.V. Leontiev said about it: "The functioning of such discontinuous in time economic processes is more difficult to understand and explain than an economic system the dynamics of which is described with the help of additive components changing without jumps" $[6,151]$. Well, as for the difficulty of understanding and explaining, it is a matter of opinion, but as for describing, such problems for a given $N(t)$ are solved by the Duhamel integral. Here we solve a simple problem, where in the equilibrium market demand suddenly changes $P$ times, from the initial value of $N_{0}$ to $P \cdot N_{0}$, and we have to determine how the price of meat products must change over time $x(t)$, (and with it, demand) to reproduce the new herd level, with minimal loss of profit for the manufacturer. Clearly, for $P>1$ demand has actually increased, and for $P<1$ it has actually fallen. The new equilibrium herd level with increased demand can be found from the equation $M_{0}=\left(\frac{N_{0}}{\lambda}\right) \cdot \operatorname{Exp}\left(-\frac{x}{\alpha}\right)$, which implies that if $N_{0}$ changes by a factor $P$, so must the herd, i.e. the new equilibrium herd will be $P \cdot M_{0}$.

Let us consider the optimal market profit in the initial and "final" states, i.e. before and after the demand jump. Initial producer profit is:

$$
\begin{equation*}
q_{0}=N_{0} \cdot\left(x_{0}-s\right) \cdot \operatorname{Exp}\left(-\frac{x_{0}}{\alpha}\right)-\eta \cdot M_{0} \tag{3}
\end{equation*}
$$

here the first summand is the profit on sale, taking into account the cost of production of meat $s$, and the second summand is the loss-cost of maintaining the entire herd, and $x_{0}$ is the initial optimum market
price. As can be easily shown, from $\frac{\partial q_{0}}{\partial x_{0}}=0$, for the value of this price we obtain the following:

$$
\begin{equation*}
x_{0}=\alpha+s+\frac{\eta}{\lambda} . \tag{4}
\end{equation*}
$$

Similarly, for profits in the final state, we have:
$q_{M}=\left(N_{0} \cdot P\right) \cdot\left(x_{0}-s\right) \cdot \operatorname{Exp}\left(-\frac{x_{0}}{\alpha}\right)-\eta \cdot P \cdot M_{0} \equiv P \cdot q_{0}$,
with the same price of $x_{0}$. For an intermediate disequilibrium market state between (3) and ( $3^{\prime}$ ), the current profit at time $t$ will be:
$q(t)=N(t) \cdot[x(t)-s] \cdot \operatorname{Exp}\left[-\frac{x(t)}{\alpha}\right]-\eta \cdot M(t)$,
and this difference $\Delta q=\left[q_{M}-q(t)\right]$, integrated at the time interval T since the demand spike and will give the market loss at the interval T. Recall that profit is in the "velocity" dimension, [\$/day], so the integral of it in time will give the sum of the loss in the interval of integration. The interval T itself is defined by the point in time when the herd reaches its new optimum level of $P \cdot M_{0}$. Finally, the market loss will be:

$$
\begin{gather*}
\int \Delta q \cdot d \tau \equiv \int\left\{P \cdot q_{0}+\eta \cdot M(\tau)-N(\tau) \cdot[x(\tau)-s] \cdot\right. \\
\left.\cdot \operatorname{Exp}\left[-\frac{x(\tau)}{\alpha}\right]\right\} \cdot d \tau \tag{6}
\end{gather*}
$$

where the integral is taken on the time interval [ $0 \leq \tau \leq T$ ], but we do not yet know the value of $T$. he mass dynamics equation (1), for a demand jump equal to $\left(N_{0} \cdot P\right)$ will be $M^{\prime}=\lambda \cdot M(t)-\left(N_{0} \cdot P\right)$. $\cdot \operatorname{Exp}\left(-\frac{x}{\alpha}\right)$, where the price formula is:

$$
\begin{equation*}
x(t)=-\alpha \cdot \operatorname{Ln}\left\{\frac{\left[\lambda \cdot M(t)-M^{\prime}\right]}{N_{0} \cdot P}\right\} . \tag{7}
\end{equation*}
$$

Substituting these equations into the total loss equation (6), we obtain the following:

$$
\begin{gather*}
\int \Delta q \cdot d \tau=\int\left\{P \cdot q_{0}+\eta \cdot M(\tau)-\left(N_{0} \cdot P\right) \cdot[x(t)-s] \cdot\right. \\
\left.\cdot \operatorname{Exp}\left[-\frac{x(t)}{\alpha}\right]\right\} \cdot d \tau \tag{6'}
\end{gather*}
$$

We then minimize equation ( $6^{\prime}$ ) as a function having in the integrand the unknown function $M(t)$ and its derivative $M^{\prime}$, included in equation (7). The
optimization of ( $6^{\prime}$ ) is not difficult, and consists in solving the equation $\frac{\partial\{\Delta q\}}{\partial M}=\frac{d \frac{[\partial\{\Delta q\}}{\partial M^{\prime}}}{\partial t}$. Finally, after transformations, we obtain the dependence of the optimal price $x(t)$ on time:

$$
\begin{equation*}
x(t)=x_{0}+C \cdot \alpha \cdot \operatorname{Exp}(-\lambda \cdot t), \tag{8}
\end{equation*}
$$

where: $C-$ is a dimensionless parameter to be determined. As we can see, if the demand increases by $P$ times, we should first raise the price to the level of $\left(x_{0}+\right.$ $+C \cdot a)$ and further decrease it according to equation (8). This sharp increase in price will provide the necessary "initial" growth of the herd, and its gradual decrease will provide the optimal growth of profit with the growth of the herd. It follows from (8) that the optimal price $x_{0}$ will only be established at $t=>8$ or at $T=8$. There is no paradox here, because such reactions to parameter changes (called relaxation) is a common natural phenomenon and takes place after fires, disasters, when some kind of "habitat" is restored again.


Now let's determine the value of parameter $C$. Let us return to equation (2) of mass dynamics, but for our specific case of demand surge. Substituting in (2) the optimal $x(\tau)=x_{0}+C \cdot a \cdot \operatorname{Exp}(-\lambda \cdot \tau)$, with the limit values $N(\tau)=\mathrm{N}_{0} \cdot P$ and $M(T)=M_{0} \cdot P$ and integrating within $[0 \leq \tau \leq T]$, we obtain, after simple transformations, the following equation:

$$
\begin{equation*}
P \cdot Z=1-\frac{[\operatorname{Exp}(-C-Z)-\operatorname{Exp}(-C)] \cdot P}{C} \tag{9}
\end{equation*}
$$

where $Z=\operatorname{Exp}(-\lambda \cdot T)$. Since for our case $T=8$, to determine the parameter $C$ the equation will be simplified as follows:

$$
\begin{equation*}
C=[1-\operatorname{Exp}(-C)] \cdot P, \tag{10}
\end{equation*}
$$

The solution of this equation (10) $C=C(P)$ is given in Picture 1 (to the left), including the case when $P<1$, i.e. when demand falls sharply (rather than increases). For values $P \approx 1$, the approximation $C \approx 2 \cdot(P-1)$, is valid, and practically "ideally" the curve $C(P)$ is approximated by: -0.3233

$$
\begin{equation*}
C(P)=2 \cdot(P-1) \cdot P \tag{11}
\end{equation*}
$$

Figure 1. Optimal parameters $C$ and $D$ meat products market

As shown in [5], in the equilibrium market, seller's profit is equal to buyer's profit (profit parameter a in models), therefore it follows from the last equation that when demand increases by $100 \cdot(P-1) \%$, price jump should be equal to:

$$
\begin{equation*}
\Delta P=2 \cdot(P-1) \cdot a \tag{12}
\end{equation*}
$$

(or it is equal to the doubled percentage of demand jump taken in relation to sellers' profit), and then it should decrease exponentially, and price should de-
crease to the previous value $x_{0}$. Let's give an example. Let the manufacturer's profit be $a=1.53 \$ / \mathrm{kg}$. Demand increased by 75\% ( $P=1.75$ ). From (11) we find that $C(1.75) \approx 1.252$. From (8) we have a price in dynamics $x(t)=x_{0}+1.915 \cdot \operatorname{Exp}(-\lambda \cdot t)$.

If we consider a constant demand market in which the number of herd changes by jumps (epidemics, mass slaughter, or "requisitioning" herd from the defeated side after a war), then this problem
is equivalent to the one already discussed, with the leap parameter $P$ replaced by $\frac{1}{P}$. I note that these problems arise in other branches (forestry, fishery), where unexpected losses of raw material sources require a long time for their own recovery. Here we assume by default that foreign trade as a faster loss compensation factor (export-import) is absent.

In the case of a supply surge for the optimal price we obtain:

$$
x(t)=x_{0}+D \cdot a \cdot \operatorname{Exp}(-\lambda \cdot t)
$$

where: $D$ is a parameter, like $C$ in the previous case. It is already valid for: -0.6767

$$
\begin{equation*}
D(P)=2 \cdot(1-P) \cdot P \tag{11'}
\end{equation*}
$$

The graph of the function $D=D(P) \mathrm{s}$ shown in
only be used for countries isolated from external markets, otherwise the dynamics of the process are significantly distorted.

Conclusion. The equations of dynamics for the prices of the market of meat products at sharp jumps in its demand and supply are solved in the first approximation. Formulas for calculating price changes over time have been provided to minimize losses from such market shocks. It is shown that, in a linear approximation, the initial response of the market should consist of a jump change in price by double the percentage of the "shock" multiplied by the optimal profit that took place at the equilibrium market state, and then in its "exponential" approximation to the previous optimal price.

Figure 1 (to the right). Formulas (8, 11, 8', 11') can

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