Does permanent income spur innovation?
A case study of oil refining

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Abstract

From 1932 through 1957, purchases of gasoline and motor oil may have related to transitory income, perhaps through impulsive purchases. This relation may have affected innovations to refine oil. [JEL O33, N52]

I. Introduction

Denote a random event that affects conditions for a while as a "sustained shock." Though the event is random, its effects may last and hence eventually be predicted. For example, as a random event, World War I might have popularized motor vehicles. This shock might have permanently raised the demand for gasoline and thus for ways to refine more gas from a barrel of crude oil.

In a time series, ordinary regression may not show clearly the impact of sustained shocks, since these need not transmit directly through autocorrelated error terms. Instead, sustained shocks may first affect explanatory variables. It may be hard to distinguish these indirect sustained shocks from transient shocks that also affect the explanatory variables. It may thus be hard to trace how indirect sustained shocks affect the dependent variable. For example, oil refineries may have looked to household income to signal higher demand for their products and thus a higher value for innovations in making those products. But a typical explanatory variable for income may not distinguish between permanent income and transitory income.[2] Disentangling their effects on innovation may lend insight, if only into whether innovation tends to follow the business cycle.

An instrumental variable may trace the effects of permanent income on a measure of innovation such as patents. Here is the approach: Regress income on a time variable that directly transmits systematic shocks; from this regression, construct a series for permanent income; finally, regress the number of patents on permanent income.[3]

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[2] Friedman (1957, chapter 3).

[3] This approach differs from that of Friedman and others (such as Thurston, 1979) who estimate permanent income from an expectation based on a distributed-lag model of past incomes. This paper instead views permanent income as the annual average return to wealth, rW, where r is the average annual rate of return to wealth in future years and W is the stream of returns to assets in future years (Laumas, 1969). Since wealth is not static, one may not be able to reliably forecast permanent income from past incomes. One may instead prefer to forecast permanent income from the stable part of current income on the assumption that other agents are paying returns to wealth on the basis of rational expectations. The approach is analogous to Smith's view of the landowner's real wealth as proportional to his net rent (Book II, chapter II). A problem with the approach of this paper, however, is that it takes no account of barriers to borrowing with human capital as collateral. Such barriers may lower the current return to wealth below the average future return; thus would current stable income understate permanent income.

Using permanent income as an instrumental variable may also avoid transitory shocks that affect both income and patents. Such shocks may render the income coefficient inconsistent.[4]

This model posits that sustained shocks may affect innovation through stages. Once estimated, permanent income helps determine a measure of permanent gas spending; then the two simulated variables help determine the number of patents granted. The model does not simultaneously determine permanent income, permanent gas spending, and number of patents.

Section II models the innovator who discriminates in prices. The firm will innovate until the revenue from high-value customers equals the cost of innovating, at the margin. High-value customers may be those with a high permanent income. Section III presents estimates of the modeling. As lifelong concepts, permanent income and gasoline spending may expunge the effects of temporary events, such as the Great Depression and the gasoline rationing of World War II. Section IV presents empirical results. Transitory income may powerfully affect spending on gasoline, perhaps because travel decisions are impulsive. To decide how much to spend on research and development in the long run, refineries may turn instead to factors that are easier than are impulsive purchases to forecast in the long run, such as the output of crude oil. Section V concludes.

II. Model

The model roots in a familiar one of the monopolist who practices second-degree price discrimination by distinguishing between product markets (Wolfstetter, 1999). Denote purchased amounts of low-octane gasoline as x_1 and purchased amounts of high-octane gasoline as x_2. The buyers' willingness to pay for another gallon of gasoline of type i is $P_i(x_i)$, $i = 1,2$. For any purchased amount, buyers are willing to pay more for high-octane gasoline than for the low-octane type: $P_2(x) > P_1(x)$.

Revenues to the monopolist from selling gasoline of type i are T_i. It spends R to research and develop high-octane gas. The amount spent depends positively on the means $\boldsymbol{\mu}$ and negatively on the dispersions $\boldsymbol{\sigma}$ of market variables, such as the amount demanded of high-octane gas: $R = R(\boldsymbol{\mu}, \boldsymbol{\sigma})$, where $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ are vectors.

If fully informed, the monopolist could project the demand for an innovation from a linear combination of n random variables Z_i that all have, as their mean, the market size. The linear combination is[5]

$$\sum_{i=1}^{n} \alpha_i Z_i .$$

Estimating the variance of the linear combination, however, requires knowledge of the full covariance matrix:

$$Var\left[\sum_{i=1}^{n} \alpha_i Z_i\right] = \alpha^T M \alpha,$$

[4] Christ (1966).

[5] I draw upon Wolfstetter (1999, Appendix D) for ideas about statistics.

where

$$\alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ . \\ . \\ . \\ \alpha_n \end{bmatrix}$$

and $\boldsymbol{\alpha}^{\boldsymbol{T}}$ is the transpose of $\boldsymbol{\alpha}$, and $\boldsymbol{M}$ is the covariance matrix:

$$M = \begin{bmatrix} \mathrm{cov}(Z_1, Z_1) & \mathrm{cov}(Z_1, Z_2) & ... & \mathrm{cov}(Z_1, Z_n) \\ . & & & \\ . & & & \\ . & & & \\ \mathrm{cov}(Z_n, Z_1) & \mathrm{cov}(Z_n, Z_2) & ... & \mathrm{cov}(Z_n, Z_n) \end{bmatrix}.$$

The firm is likely to have in hand only variances of market variables – that is, the cross-diagonal of $\boldsymbol{M}$ – rather than all covariances. One may then speculate that the firm would make a preliminary forecast of the demand for its innovation from only the market variable Z_j that has the smallest variance of all Z_i's. If, from this forecast, it cannot expect to make money, then it is unlikely that expanding the forecast to include higher-variance variables would change the conclusion; for they all have the same mean.

For example, denote the firm's utility of profits as $U(x)$, and assume a normal distribution for profits x, with mean μ and variance σ^2. Then one may model the expected utility of profits as

$$E[U(x)] = -e^{-r(\mu - r\sigma^2/2)}$$

where r is the degree of absolute risk aversion. Certainty-equivalent profits are x_0 that satisfy

$$U(x_0) = U[E(U[X])].$$

Then

$$x_0 = \mu - r\sigma^2 / 2.$$

This increases as σ^2 diminishes. A forecast of demand that uses the random variable for profits that has the smallest variance is analogous to a forecast that uses the highest certainty-equivalent profits.

In sum, the firm with partial information may substitute for $R(\boldsymbol{\mu}, \boldsymbol{\sigma})$ the *R&D* function $R(\mu_m, \sigma_m)$, where μ_m and σ_m are the mean and the variance of the minimum-variance random variable for profits.

R&D spending may improve high-octane gasoline, raising $P_2(x_2, R)$, or lower the production cost. The development and production cost is $C_2(R)$, where the derivative is positive if another dollar of R&D spending does not reduce production cost by a full dollar. The cost of producing low-octane gasoline is set to zero.

The monopolist seeks to extract full surplus from low-octane buyers and as much surplus as it can from high-octane buyers, since it exerts greater power over the low-octane market than over the high-octane one. Thus

$$T_1 = \alpha \int_0^{x_1} P_1(x, y_1)\, dx$$

where the income of low-octane buyers, y_1, raises the willingness to pay for the gasoline; and $\alpha \in [0,1]$ is a market-power parameter that reflects the firm's ability to capture consumer surplus.

Higher-income buyers may purchase low-octane gasoline as well as high-octane gas at the prices that prevail in the two markets. Higher-income buyers prefer high-octane gas to reduce engine knock, but they purchase low-octane gas as well because it is a bargain for them. Thus

$$T_2 = T_1 + \alpha \int_{x_1}^{x_2} P_2(x, y_2, R)\, dx \geq C(R).$$

Assuming an interior solution, the monopolist spends on research and development until satisfying

$$\alpha \int_{x_1}^{x_2} \frac{\partial P_2}{\partial R}\, dx = \frac{\partial C}{\partial R}.$$

Thus higher income need not spur R&D spending if it simply raises the quantity demanded in both markets proportionally, leaving $x_2 - x_1$ unchanged. Higher income will stimulate R&D, however, if it increases the value of the product.

III. Estimates

The analysis spans 1932 through 1957. It estimates permanent income by regressing actual income on a time trend (*Year*) and on a proxy variable for the years of the Great Depression (*Depression*). Actual income is in per capita terms, adjusted by the Consumer Price Index into 1958 dollars. The regression equation generates estimates of permanent income:

Permanent income per capita = -58657 + 31.3666 *Year* – 591.28 *Depression*.

The analysis then regresses annual spending on gasoline and motor oil upon *Permanent income per capita*; a time trend (*Year*); and upon a control for gas rationing during World War II (*WarGrow*). Actual spending on gasoline is in 1967 dollars, adjusted by the CPI. This regression equation generates estimates of permanent gas spending:

Permanent gas spending = -1168645 – 4.514 *Permanent income per capita* + 609.58 *Year* – 1159.8 *WarGrow*

Patents data are from Schmookler (1972). All other time series are from the *Historical statistics of the United States* (1975).

Variable	**Observations**	**Mean**	**Median**	**Standard deviation**
Simulated income per capita	26	2130.7	2335.4	503.3
Military capital	26	25716	15701	27843
Patents	26	280.3	244.0	95.2
Simulated gas	26	6798	6540	2888

Figure 1: Descriptive statistics for simulation model

IV. Results

The model below regresses personal consumer spending on gasoline and motor oil, in real terms (*Gas*), upon *Permanent income per capita*; on a time trend (*Year*); and on a dummy variable for war rationing in 1942-1944 (*War rationing*).

The results suggest that transitory income may markedly boost the demand for gasoline, perhaps through unplanned travel for pleasure. This reflection arises from the negative effect on gasoline spending of *Permanent income per capita*. A rise in permanent income per capita of $1 corresponds to a rise in national gas spending of $4.5

billion (the former in 1958 dollars; the latter in 1967 dollars). Evaluated at the means, the elasticity of gas demand with respect to permanent income is –1.41.

If many purchases of gasoline are impulsive, then rationing may cut spending severely. At the margin, rationing during World War II seems to have cut gas spending more sharply than technological innovation increased it: An additional year of rationing reduces gas spending by $2.27 billion, while an additional year in the time trend increases gas spending by $609 million (both figures in 1958 dollars).

Gas = - 1168261 - 4.51 *Permanent income per capita* - 2272 *War rationing* + 609 *Year*		
26 observations	Adjusted R^2 = .938	
Variable	**Coefficient**	**Standard deviation**
Constant	-1168261	114079
Permanent income per capita	-4.514	1.209
War rationing	-2272.1	865.5
Year	609.38	59.89

Figure 2: Model of spending on gasoline

The effects of rationing may accumulate over time as regulators learn how to avert gas purchases. The linear model underestimates the reduction in gas spending during the war when it uses a binary variable for rationing. This suggests that gas rationing may have become more effective over the course of the war. The next run changes the dummy variable from a binary form into one that counts the number of years of rationing (*War rationing plus*). This slightly improves the accuracy of the model; adjusted R^2 rises from .938 to .941.

Gas = - 1168645 - 4.51 *Permanent income per capita* + 610 *Year* - 1160 *War rationing plus*		
26 observations	Adjusted R^2 = .941	
Variable	**Coefficient**	**Standard deviation**
Constant	-1168645	109019
Permanent income per capita	-4.514	1.158
Year	609.58	57.24
War rationing plus	-1159.8	380.8

Figure 3: Model of spending on gasoline with new measure of rationing

Continued rationing may so reduce gas spending as to dissuade the innovation of ways to produce more gas. To study the matter, the number of patents granted per year is regressed upon *Permanent gas spending* (which reflects the impact of rationing); *Permanent income per capita*; and upon a measure of spending upon physical capital in the defense sector, expressed in 1967 dollars, adjusted by the CPI (*Military capital*). An additional year of wartime rationing of gasoline would have decreased the annual number of patents by 17 – that is, by more than a tenth at the end of World War II.

More surprising is the negative impact of permanent income on innovation. A $100 fall in per capita income is associated with a rise of 13 in the annual number of patents. The effect is somewhat modest: Evaluated at the means, the elasticity of the number of patents with respect to permanent income is -.89. Most of this effect, however, occurs directly; less than one-sixth of the effect occurs indirectly, through a rise in gasoline spending. As permanent income falls, firms may anticipate that households will spend relatively more on impulsive purchases; and they may spend relatively more on that line of research and development in order to satisfy that shift in demand.

Patents = 520 - 0.117 *Permanent income per capita* -0.000561 *Military capital* + 0.00368 *Permanent gas spending*		
26 observations	*Adjusted* R^2 = .364	
Variables	**Coefficients**	**Standard deviation**
Constant	519.75	82.24
Permanent income per capita	-0.11735	0.06788
Military capital	-0.0005614	0.0008653
Permanent gas spending	0.003680	0.009770

Figure 4: Estimates of simulation model

V. Conclusions and reflections

During the formative decades of the automobile market, the purchase of gasoline and motor oil seems to have related more to transitory income than to permanent income. Perhaps, when these products were relatively novel, buyers often acted on impulse. If purchases were transitory, then rationing them might sharply cut both the purchases as well as the number of related innovations undertaken by firms. Statistical evidence is consistent with that idea.

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