Table 11.3b *2SLS* **Estimates for Truffle Supply**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	20.0328	1.2231	16.3785	0.0000
P	0.3380	0.0249	13.5629	0.0000
PF	−1.0009	0.0825	−12.1281	0.0000

have statistically significant coefficients and thus have an effect upon the quantity demanded.

The supply equation results appear in Table 11.3b. As anticipated, increases in the price of truffles increase the quantity supplied, and increases in the rental rate for truffle-seeking pigs, which is an increase in the cost of a factor of production, reduces supply. Both of these variables have statistically significant coefficient estimates.

11.7 Supply and Demand at the Fulton Fish Market

The Fulton Fish Market has operated in New York City for over 150 years. The prices for fish are determined daily by the forces of supply and demand. Kathryn Graddy[2] collected daily data on the price of whiting (a common type of fish), quantities sold, and weather conditions during the period December 2, 1991 to May 8, 1992. These data are in the file *fultonfish.dat*. Fresh fish arrive at the market about midnight. The wholesalers, or dealers, sell to buyers for retail shops and restaurants. The first interesting feature of this example is to consider whether prices and quantities are *simultaneously* determined by supply and demand at all.[3] We might consider this a market with a fixed, perfectly inelastic supply. At the start of the day, when the market is opened, the supply of fish available for the day is fixed. If supply is fixed, with a vertical supply curve, then price is demand determined, with higher demand leading to higher prices, but no increase in the quantity supplied. If this is true then the feedback between prices and quantities is eliminated. Such models are said to be **recursive** and the demand equation can be estimated by ordinary least squares rather than the more complicated two-stage least squares procedure.

However whiting fish can be kept for several days before going bad, and dealers can decide to sell less, and add to their inventory, or buffer stock, if the price is judged too low, in hope for better prices the next day. Or, if the price is unusually high on a given day, then sellers can increase the day's catch with additional fish from their buffer stock. Thus despite the perishable nature of the product, and the daily resupply of fresh fish, daily price is simultaneously determined by supply and demand forces. The key point here is that "simultaneity" does not require that events occur at a simultaneous moment in time.

Let us specify the demand equation for this market as

$$\begin{aligned}\ln(QUAN_t) = \alpha_1 + \alpha_2\ln(PRICE_t) + \alpha_3 MON_t + \alpha_4 TUE_t + \alpha_5 WED_t \\ + \alpha_6 THU_t + e_t^d\end{aligned} \qquad (11.13)$$

[2] See Kathryn Graddy (2006) "The Fulton Fish Market," *Journal of Economic Perspectives*, 20(2), 207–220. The authors would like to thank Professor Graddy for permission to use the data from her study.

[3] The authors thank Peter Kennedy for this observation. See Kathryn Graddy and Peter E. Kennedy (2006) "When are supply and demand determined recursively rather than simultaneously? Another look at the Fulton Fish Market data," working paper. See http://www.economics.ox.ac.uk/members/kathryn.graddy/research.htm.

where $QUAN_t$ is the quantity sold, in pounds, and $PRICE_t$ the average daily price per pound. Note that we are using the subscript "t" to index observations for this relationship because of the time series nature of the data. The remaining variables are dummy variables for the days of the week, with Friday being omitted. The coefficient α_2 is the price elasticity of demand, which we expect to be negative. The daily dummy variables capture day-to-day shifts in demand. The supply equation is

$$\ln(QUAN_t) = \beta_1 + \beta_2 \ln(PRICE_t) + \beta_3 STORMY_t + e_t^s \tag{11.14}$$

The coefficient β_2 is the price elasticity of supply. The variable $STORMY$ is a dummy variable indicating stormy weather during the previous 3 days. This variable is important in the supply equation because stormy weather makes fishing more difficult, reducing the supply of fish brought to market.

11.7.1 Identification

Prior to estimation, we must determine if the supply and demand equation parameters are identified. The necessary condition for an equation to be identified is that in this system of $M = 2$ equations, it must be true that at least $M - 1 = 1$ variable must be omitted from each equation. In the demand equation the weather variable $STORMY$ is omitted, but it does appear in the supply equation. In the supply equation, the four daily dummy variables that are included in the demand equation are omitted. Thus the demand equation shifts daily, while the supply remains fixed (since the supply equation does not contain the daily dummy variables), thus tracing out the supply curve, making it identified, as shown in Figure 11.4. Similarly, stormy conditions shift the supply curve relative to a fixed demand, tracing out the demand curve, and making it identified.

11.7.2 The Reduced Form Equations

The reduced form equations specify each endogenous variable as a function of all exogenous variables

$$\begin{aligned}\ln(QUAN_t) = {} & \pi_{11} + \pi_{21} MON_t + \pi_{31} TUE_t + \pi_{41} WED_t + \pi_{51} THU_t \\ & + \pi_{61} STORMY_t + v_{t1}\end{aligned} \tag{11.15}$$

$$\begin{aligned}\ln(PRICE_t) = {} & \pi_{12} + \pi_{22} MON_t + \pi_{32} TUE_t + \pi_{42} WED_t + \pi_{52} THU_t \\ & + \pi_{62} STORMY_t + v_{t2}\end{aligned} \tag{11.16}$$

These reduced form equations can be estimated by least squares because the right-hand-side variables are all exogenous and uncorrelated with the reduced form errors v_{t1} and v_{t2}. Using the Graddy's data (*fultonfish.dat*) we estimate these reduced form equations and report them in Table 11.4. Estimation of the reduced form equations is the first step of two-stage least squares estimation of the supply and demand equations. It is a requirement for successful two-stage least squares estimation that the estimated coefficients in the reduced form for the right-hand-side endogenous variable be statistically significant. We have specified the

Table 11.4a Reduced Form for ln(Quantity) Fish

Variable	Coefficient	Std. Error	*t*-Statistic	Prob.
C	8.8101	0.1470	59.9225	0.0000
STORMY	−0.3878	0.1437	−2.6979	0.0081
MON	0.1010	0.2065	0.4891	0.6258
TUE	−0.4847	0.2011	−2.4097	0.0177
WED	−0.5531	0.2058	−2.6876	0.0084
THU	0.0537	0.2010	0.2671	0.7899

Table 11.4b Reduced Form for ln(Price) Fish

Variable	Coefficient	Std. Error	*t*-Statistic	Prob.
C	−0.2717	0.0764	−3.5569	0.0006
STORMY	0.3464	0.0747	4.6387	0.0000
MON	−0.1129	0.1073	−1.0525	0.2950
TUE	−0.0411	0.1045	−0.3937	0.6946
WED	−0.0118	0.1069	−0.1106	0.9122
THU	0.0496	0.1045	0.4753	0.6356

structural equations (11.13) and (11.14) with ln(*QUAN*) as the left-hand-side variable and ln(*PRICE*) as the right-hand-side endogenous variable. Thus the key reduced form equation is (11.16) for ln(*PRICE*). In this equation

- To identify the supply curve, the daily dummy variables must be jointly significant. This implies that at least one of their coefficients is statistically different from zero, meaning that there is at least one significant shift variable in the demand equation, which permits us to reliably estimate the supply equation.
- To identify the demand curve, the variable *STORMY* must be statistically significant, meaning that supply has a significant shift variable, so that we can reliably estimate the demand equation.

Why is this so? The identification discussion in Section 11.4 requires only the presence of shift variables, not their significance. The answer comes from a great deal of econometric research in the past decade, which shows that the two-stage least squares estimator performs very poorly if the shift variables are not strongly significant.[4] Recall that to implement two-stage least squares we take the predicted value from the reduced form regression and include it in the structural equations in place of the right-hand-side endogenous variable. That is, we calculate

$$\widehat{\ln(PRICE_t)} = \hat{\pi}_{12} + \hat{\pi}_{22}MON_t + \hat{\pi}_{32}TUE_t + \hat{\pi}_{42}WED_t + \hat{\pi}_{52}THU_t + \hat{\pi}_{62}STORMY_t$$

where $\hat{\pi}_{k2}$ are the least squares estimates of the reduced form coefficients, and then replace ln(*PRICE*) with $\widehat{\ln(PRICE_t)}$. To illustrate our point let us focus on the problem of

[4] See James H. Stock and Mark W. Watson (2007) *Introduction to Econometrics, 2nd edition,* Pearson Education, Appendix 12.5 for a more technical, but still intuitive discussion.

Table 11.5 2SLS Estimates for Fish Demand

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C Sabit Terim	8.5059	0.1662	51.1890	0.0000
ln($PRICE$) ln(Fiyat)	−1.1194	0.4286	−2.6115	0.0103
MON	−0.0254	0.2148	−0.1183	0.9061
TUE Kuklalar	−0.5308	0.2080	−2.5518	0.0122
WED	−0.5664	0.2128	−2.6620	0.0090
THU	0.1093	0.2088	0.5233	0.6018

estimating the supply equation (11.14) and take the extreme case that $\hat{\pi}_{22} = \hat{\pi}_{32} = \hat{\pi}_{42} = \hat{\pi}_{52} = 0$, meaning that the coefficients on the daily dummy variables are all identically zero. Then

$$\widehat{\ln(PRICE_t)} = \hat{\pi}_{12} + \hat{\pi}_{62} STORMY_t$$

If we replace ln($PRICE$) in the supply equation (11.14) with this predicted value, there will be *exact* collinearity between $\widehat{\ln(PRICE_t)}$ and the variable $STORMY$, which is already in the supply equation, and two-stage least squares will fail. If the coefficient estimates on the daily dummy variables are not exactly zero, but are jointly insignificant, it means there will be severe collinearity in the second stage, and while the two-stage least squares estimates of the supply equation can be computed, they will be unreliable. In Table 11.4b, showing the reduced form estimates for (11.16), none of the daily dummy variables are statistically significant. Also, the joint F-test of significance of the daily dummy variables has p-value 0.65, so that we cannot reject the null hypothesis that all these coefficients are zero.[5] In this case the supply equation is not identified in practice, and we will not report estimates for it.

However, $STORMY$ is statistically significant, meaning that the demand equation may be reliably estimated by two-stage least squares. An advantage of two-stage least squares estimation is that each equation can be treated and estimated separately, so the fact that the supply equation is not reliably estimable does not mean that we cannot proceed with estimation of the demand equation. The check of statistical significance of the sets of shift variables for the structural equations should be carried out each time a simultaneous equations model is formulated.

11.7.3 Two-Stage Least Squares Estimation of Fish Demand

Applying two-stage least squares estimation to the demand equation we obtain the results as given in Table 11.5. The price elasticity of demand is estimated to be −1.12, meaning that a 1% increase in fish price leads to about a 1.12% decrease in the quantity demanded, and this estimate is statistically significant at the 5% level. The dummy variable coefficients are negative and statistically significant for Tuesday and Wednesday, indicating that demand is lower on these days relative to Friday.

[5] Even if the variables are jointly significant there may be a problem. The significance must be "strong." An F-value <10 is cause for concern. This problem is the same as that of weak instruments in instrumental variables estimation. See Section 10.4.2.