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Learning and price volatility in duopoly models of resource depletion

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ABSTRACT

The combination of learning and depletion in non-renewable resource markets adds significant volatility to commodity prices. The market consists of a small number of suppliers who make depletion plans based on their perceptions of how sensitive price is to supply. Learning leads to changes in these perceptions and hence the revision of depletion plans, which can have a dramatic effect on market supply and price. Firstly, price trends upwards faster than the rate of time preference as the non-renewable resource approaches exhaustion. Secondly, there are frequent escape episodes in which price rises rapidly before gradually falling back. The striking volatility and nonstationarity in commodity prices that results has parallels in oil price data.

1. Introduction

A number of recent papers have explored the potential for learning and associated changes in agents' beliefs to create interesting economic dynamics. Marcet and Sargent (1989) focus on whether dynamics converge on a Rational Expectations Equilibria. Evans and Honkapohja (1995) investigate issues of E-stability and how learning can generate stable or unstable fluctuations. Bullard and Mitra (2002) show the relevance of this issue for the evaluation of monetary policy rules. In a series of seminal papers, Fudenberg and Levine (1993a, 1993b, 2009) analyse the concept of a Self Confirming Equilibrium and its relationship to Nash (and Rational Expectations) Equilibria. The concept of a Self Confirming Equilibrium and the possibility of escape dynamics that arise are examined by Sargent (1999), Cho et al. (2002) and Sargent et al. (2009), who consider cases of inflation and hyperinflation in the Americas. This paper extends this literature by introducing learning into a new setting – non-renewable commodity markets. Non-renewable commodities introduce issues of depletion planning into the analysis, and this fundamentally affects the nature of learning dynamics. As a result of the interaction of learning and depletion planning, there is substantially greater volatility in non-renewable commodity prices at both low and high frequencies.

The application of learning to commodity markets is a novel one. Most of the papers cited above relate to inflation and monetary policy issues. In addition, Lettau and Uhlig (1999) consider the implications of learning for aggregate consumption fluctuations, Adam et al. (2007) introduce learning into the analysis of stock markets and Piazzesi and Schneider (2007)

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show how learning can add important and empirically plausible dynamics to yield curve fluctuations. However, as noted by Deaton and Laroque (1996), commodity prices show a persistence and volatility that is hard to explain with reference to underlying shocks, making them a natural candidate with which to explore the propagation role of learning in price dynamics. Williams (2001) offers a general duopoly model of a product market and shows how escape dynamics provide additional volatility.[1] This paper uses Williams' model as a starting point, but critically adds the assumption that the product being supplied is non-renewable.

The extension of Williams' model to the case of non-renewable commodities is important. Firstly, unlike agricultural commodity markets, non-renewable commodities such as oil, copper, platinum and tin are by definition characterised by a finite stock of available resource. As a consequence, these commodities are often found in the control of a small number of suppliers, an obvious case being OPEC. Reflecting this, the seminal work on non-renewable commodities has always involved firms with market power, e.g. Hotelling (1931), Dasgupta and Heal (1974), Salant (1976), Stiglitz and Dasgupta (1982), and Loury (1986). The fact that firms have market power is critical if learning and escape dynamics are to generate important fluctuations. The second important feature of non-renewable commodities is it introduces a role for depletion plans. We show how depletion fundamentally impacts on market dynamics.

Hotelling (1931) shows how non-renewable commodities should optimally see their price trend upwards at the rate of time preference. In the Rational Expectations version of our model there are both cooperative and non-cooperative equilibria, with cooperation characterised by suppliers setting a high price and a low quantity, and non-cooperation having suppliers setting a low price and a high quantity. The price of the non-renewable resource trends upwards at the rate of time preference in both cases. When learning is introduced to the model, it is shown that the market is in non-cooperative equilibrium if the stock of non-renewable resource is large relative to demand, whereas it is in cooperative equilibrium if the stock of non-renewable resource is small relative to demand. With the stock of resources inevitably falling as firms supply in a non-renewable commodity setting, the market evolves over time from a non-cooperative to a cooperative equilibrium. Depletion of the non-renewable resource therefore acts as a coordinating device, which in the context of the model occurs because of evolution in the self confirming equilibrium.

The price of a non-renewable resource in the model rises over time for familiar Hotelling reasons, but also because of the evolution in the self confirming equilibrium. The optimal depletion plan encourages suppliers to cut back on supply over time, which through the learning process creates the impression that demand is more sensitive to supply and gives incentives for further reductions in supply. Prices therefore rise faster than the rate of time preference, as supply contracts both because the non-renewable resource is being depleted and because suppliers perceive that demand is more sensitive. Depletion of non-renewable resources therefore coordinates the uncoordinated actions of suppliers, and the market tends towards the cooperative equilibrium. Against the backdrop of this evolution in the self confirming equilibrium, the non-renewable commodity market in the model also exhibits escape dynamics. These take the form of shifts in the market from the mean dynamics towards the cooperative equilibrium. The presence of escape dynamics leads to large but infrequent jumps in prices, especially when the stock of non-renewable resource is large relative to demand. The mean dynamics become increasingly close to the cooperative equilibrium as the stock of non-renewable resource is depleted, so the price jumps due to escapes become less dramatic but more frequent over time.

The notion that learning can produce sharp fluctuations characterised by regime changes has been explored by others. For instance, Evans and Honkapohja (1993, 1994) focus on how shifts between multiple equilibria may cause business cycle fluctuations. A similar notion is explored by Kasa (2004), who demonstrates how escape dynamics can generate sudden changes in exchange rates and that the dynamics of Latin American currencies can be approximated using Markov switching regimes. However, these are models of multiple equilibria whereas our model has a unique equilibrium. Although depletion of the non-renewable resource in our model leads to a shift in the Self Confirming Equilibrium, there is always a unique equilibrium for any given stock of the non-renewable resource. Brock and Hommes (1997) alternatively show that learning can create substantial fluctuations in a cobweb model where many agents choose optimally between two forecasting rules. This leads to endogenous cycles as the majority of agents are induced to switch between the forecasting rules. Our model differs from theirs in that all our agents use the same forecasting rule and our fluctuations are driven by underlying changes in the stocks of non-renewable resources. As stocks of the non-renewable resource will eventually run out, the long run properties of our model are well defined and do not show strange dynamics.[2]

The commodity price volatility in the model is caused by underlying fluctuations between non-cooperative and cooperative equilibria. This is similar in spirit to the key mechanism in Green and Porter (1984) from the industrial organisation literature. In both cases the market alternates between different equilibria, but in Green and Porter (1984) there is an explicit incentive for collusion that periodically breaks down if a negative demand shock causes prices to fall below some "trigger price", at which point the self-policing cartel collapses. In our model, there is no explicit incentive for collusion and the market is characterised by both evolution and escapes from the non-cooperative equilibrium to the cooperative equilibrium. Comparing the two approaches, the emphasis in Green and Porter (1984) is on the fall in prices that follows the endogenous collapse of

[1] A more recent version of Williams (2001) was posted on Noah William's website in 2009, but the new version does not discuss the duopoly model of a product market.

[2] Kandori et al. (1993) obtain a result with a similar flavour to ours in the context of an evolutionary game. They show how mutations can restrict the long run equilibria of the model and create a shift in outcomes. In our case, having finite stocks of the non-renewable resource means that the only long run outcome of the model is the cooperative equilibrium.