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On the empirical relevance of the Lucas supply curve. (A note)

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On the empirical relevance of the Lucas supply curve.

(A note)

Claude Bismut and Ismaël Ramajo

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Abstract. In this paper we extend the usual Lucas supply curve to allow the likely external influence on inflation, together with domestic conditions. We test the relationship between the inflation surprise, the output gap and the real exchange rate using simple time series regressions on annual data for a list of 16 developed countries. These tests confirm the empirical relevance of the Lucas supply curve but also support the assumption that part of the inflation surprise may come from unexpected variations of the real exchange rate.

Keywords: Lucas supply curve, natural rate of unemployment, output gap, inflation surprise imported inflation.

Résumé. Dans cet article, nous étendons la courbe d'offre de Lucas usuelle, afin de prendre en compte de l'influence externe probable sur l'inflation, en plus des conditions intérieures. Nous testons la relation entre l'inflation, l'output gap et le taux de change réel à l'aide de simples régressions chronologiques sur des données annuelles pour une liste de 16 pays développés. Ces tests confirment la pertinence empirique de la courbe d'offre de Lucas mais confortent également l'hypothèse selon laquelle une partie de la surprise inflationniste pourrait provenir de variations inattendues du taux de change réel.

Mots clés : Courbe d'offre à la Lucas, Taux de chômage naturel, output gap, inflation surprise inflation importée.

Introduction

One important implication of the natural rate of unemployment is the existence of a relation between the inflation surprise and the output gap. This relation has been called the Lucas supply curve. This notion stands as the most compact description of the supply side in a large number of short-term dynamic macro models. In this paper we extend the Lucas supply curve in an open economy framework by allowing imported inflation. Then, we test the relationship between the inflation surprise, the output gap and the real exchange rate using simple time series regressions on annual data for a list of 16 developed countries. These tests confirm the empirical relevance of the Lucas supply curve but also suggest that part of the inflation surprise may come from unexpected variations of the real exchange rate.

1. The Lucas supply curve

The Lucas supply curve can be derived from a bloc of three equations which constitutes the supply side of a short run dynamic model, namely: a Phillips curve, a price setting equation and the Okun's law. These specifications generate a short-term trade-off between inflation

and unemployment, and a stationary state with one equilibrium rate of unemployment (the so-called natural rate of unemployment) but no equilibrium inflation rate, and therefore no trade off. There is nothing more in the Lucas supply curve, than a translation of the natural rate hypothesis in terms of output-inflation relationship. Let us now depict the argument analytically.

We consider the following supply side, short run dynamic sub-model which comprises three relations, where low case letters denote variables in log, and dots denote the time difference.

The first relation is an expectation augmented Phillips curve which sets that the change in the real wage, the difference between the rate of growth of wages \dot{w}_t , and the rate of growth of the aggregate price index \dot{p}_t , depends on the unemployment rate U_t , and the inflation surprise defined as the difference between effective inflation \dot{p}_t and expected inflation \tilde{p}_t :

$$(1) \quad \dot{w}_t - \dot{p}_t = -(1 - \theta)(\dot{p}_t - \tilde{p}_t) - \beta U_t + \gamma, \quad \text{with } \beta > 0, \gamma > 0, \text{ and } 0 \leq \theta \leq 1$$

The second relation reflects a fairly general price setting behavior of firms, where prices move one for one with unit labor costs $\dot{w}_t - \dot{g}_t$ as measured by the difference between wage increase \dot{w}_t and the increase in productivity \dot{g}_t , but also react to excess demand as measured by the output gap: the difference between the (log of) effective production y_t , and the (log of) potential production \bar{y}_t :

$$(2) \quad \dot{p}_t = \dot{w}_t - \dot{g}_t + \nu(y_t - \bar{y}_t), \quad \text{with } \nu > 0.$$

The third relation is a short run dynamic relationship between the unemployment gap and the output-gap, the so called Okun's law¹:

$$(3) \quad (U_t - \bar{U}_t) = -\zeta(y_t - \bar{y}_t), \quad \text{with } \zeta > 0.$$

From equations (1), (2), (3) one can easily get a relation between inflation surprise and the unemployment:

$$(4) \quad \dot{p}_t - \tilde{p}_t = -\frac{\zeta\beta + \nu}{\zeta(1 - \theta)}(U_t - \bar{U}_t), \quad \text{where } \bar{U}_t = \frac{\gamma - \dot{g}_t}{\beta}.$$

First, for a given value of \tilde{p}_t there exist a trade-off between inflation and unemployment. And second \bar{U}_t is the equilibrium value of unemployment consistent with no inflation surprise. This property is known as the "natural rate hypothesis"².

Finally, by a simple variable change, using again relation (3) we obtain a relation between the inflation surprise and the output gap, namely: the Lucas supply curve:

$$(5) \quad \dot{p}_t - \tilde{p}_t = \mu(y_t - \bar{y}_t), \quad \text{with } \mu = -\frac{\zeta\beta + \nu}{(1 - \theta)}.$$

This shows that assuming a Lucas supply curve or affirming the natural rate is the one and the same thing. We leave, now, the nice world of theory and we turn to more problematic issues.

¹ The literature on Okun's law is over-abundant. See for instance Ball, Leigh & Loungani (2017)

² Although it is not an assumption, but an implication of the assumptions included in (1) (2) (3).

2 Estimating the Lucas supply curve

Estimating the Lucas supply curve raises severe problems. We will focus on two of them, which are of particular importance within the scope of this short note.

2.1 Unobserved variables

Estimating the Lucas supply curve may appear as a *tour de force* when realizing that it involves testing an empirical relationship between two unobserved variables: the inflation surprise and the output gap.

The inflation surprise: is the difference between the rate of inflation \dot{p}_t , which is a statistical data produced by the national statistical institutes and the expected rate of inflation \tilde{p}_t , subjectively shaped by private agents, and for which we have no direct observations. Economic surveys provide some indications on expected inflation but are not appropriate for macro-modelling³. Implicit measures (revealed anticipations) could also be used in certain circumstances but are subject to very specific assumptions⁴. Here we have conventionally assumed that the rate of inflation this year is expected to be the same as last year.

$$(6) \quad \tilde{p}_t = E_t(\dot{p}_t) = \dot{p}_{t-1} .$$

Although very crude, this anticipation process would be rational if the rate of inflation follows a random walk, which is broadly consistent with empirical evidence⁵. Under (6) the natural rate of unemployment underlying the model would coincide with the so-called NAIRU⁶. This appears quite clearly if we replace the inflation surprise $(\dot{p}_t - \tilde{p}_t)$ by the acceleration of inflation $(\dot{p}_t - \dot{p}_{t-1})$ in equation (4). Furthermore, the Lucas supply curve, reduces to a relation between the time change in the rate of inflation and the output gap. Equation (5) becomes:

$$(7) \quad (\dot{p}_t - \dot{p}_{t-1}) = \mu(y_t - \bar{y}_t) , \text{ with } \mu = \frac{\zeta\beta + v}{(1 - \theta)} > 0$$

In practice, most empirical studies refer to the NAIRU⁷ when speaking about the natural rate of unemployment, although it is a particular case. What we have done here is subject to the same criticism, a shortcoming that could be overcome elsewhere.

The output gap $(y_t - \bar{y}_t)$ is another unobserved variable as GDP is available in national accounts, whereas potential GDP is not. However, estimates of the output gap are periodically published by a number of national and international institutions. Indeed, for economic policy purposes, it is essential to rely on some estimate of full employment and its associated level of production. National government, private institutes, the OECD and the IMF produce estimates of potential output using econometric models based on structural equations such as (1), (2), (3) and (6), thus implicitly based on the NAIRU. For example, the OECD publishes statistical tables which contains estimates of the NAIRU and the associated output gap but does not

³ Some attempts have been done in this direction. See Brochener Madsen (1997) who failed to detect any positive relation between unexpected inflation and output.

⁴ For instance, see Fama (1975) and the subsequent literature.

⁵ Aggregate price indexes are, most of the time, integrated or order two.

⁶ The NAIRU requires that expected inflation would converge to the effective inflation rate when inflation stabilizes. Equation (6) is only a sufficient condition which meets this requirement.

⁷ Including the OECD studies.

exhibit the Lucas supply curve implicitly contained in those models. Ideally, we should proceed along the same lines: estimate a multiple equation model and establish the Lucas supply curve. However, instead of estimating a full simultaneous equations system ⁸, we took a shortcut and chose to estimate directly the Lucas supply equation (7), using the estimated output gap published by the OECD (see appendix 3).

22 Domestic and imported inflation

The Lucas supply curve is generally presented in the framework of the closed economy, but we believe that for an empirical application such as the present one, openness cannot be ignored. In a closed economy, the CPI has no reason to depart from the producer price, and there is only one aggregate price index denoted by p_t . It is not the same in an open economy where consumers absorb domestic as well as imported goods, whose prices have no reason to be identical. We keep p_t to denote the producer price index and we denote by p_t^c the consumer price index (CPI) which is some weighted average of the price of domestic goods and the price of foreign goods denominated in domestic currency. We denote by p_t^* , the log of the price index of foreign goods and by e_t , the log of the nominal exchange rate. Then, the rate of inflation can be approximated by:

$$\dot{p}_t^c = \lambda \dot{p}_t + (1 - \lambda)(\dot{e}_t + \dot{p}_t^*) \quad \text{with } 0 < \lambda \leq 1 \quad ,$$

if we define the real exchange rate as $z_t = e_t + p_t^* - p_t$, we can also write:

$$(8) \quad \dot{p}_t^c - \dot{p}_t = (1 - \lambda)\dot{z}_t$$

The Philips curve has to be modified accordingly. The growth of real wage must be calculated using the consumer price index.

$$(1') \quad \dot{w}_t - \dot{p}_t^c = -(1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) - \beta U_t + \gamma$$

The producer price index itself may also be sensitive to foreign prices as domestic and foreign producers compete in the domestic market. Domestic and foreign goods are presumably imperfect substitutes thus, foreign prices, through the real exchange rate, will have an impact on producer prices together with labor costs and the output gap:

$$(2') \quad \dot{p}_t = \dot{w}_t - \dot{g}_t + \nu(y_t - \bar{y}_t) + \delta \dot{z}_t$$

We then solve the model (1'), (2'), (3), and (8) (see appendix1) and we get:

$$(5') \quad (\dot{p}_t^c - \tilde{p}_t^c) = \mu(y_t - \bar{y}_t) + \eta(\dot{p}_t^c - \dot{p}_t), \quad \text{with } \mu = \frac{\zeta\beta + \nu}{(1 - \theta)} > 0, \quad \eta = \frac{\delta + (1 - \lambda)}{(1 - \lambda)(1 - \theta)} > 0$$

Note that the natural rate of unemployment is not changed, but we have now a second factor which reflects the pressure of foreign competitors on domestic producers.

Finally, using (6) (NAIRU case) we obtain:

$$(9) \quad (\dot{p}_t^c - \tilde{p}_t^c) = \mu(y_t - \bar{y}_t) + \eta(\dot{p}_t^c - \dot{p}_t), \quad \text{the equation to be estimated.}$$

⁸ See Adams and Coe (1990).

3 Econometric evidence on the two factors model

Table 1. Estimation of the two factors model (equation (9))

Country	Sample	Output Gap	Real Exchange rate	R ² F-statistic	DW
Australia	1975-2016	0.42* (0.21)	0.24 (0.23)	0.09 1.99	2.35^{oo}
Canada	1966-2016	0.33*** (0.10)	0.00 (0.17)	0.22*** 6.65	1.97^{oo}
France	1961-2016	0.35*** (0.12)	0.84*** (0.21)	0.35*** 14.30	1.44
Germany	1966-2016	0.34*** (0.05)	0.20** (0.09)	0.51*** 24.51	1.58 ^o
Greece	1975-2016	0.16* (0.08)	0.44* (0.23)	0.15** 3.35	1.47 ^o
Ireland	1977-2016	0.13 (0.12)	0.19 (0.19)	0.05 1.08	1.57 ^o
Italy	1963-2016	0.55*** (0.12)	0.47 (0.32)	0.30*** 10.83	1.64 ^o
Japan	1970-2016	0.44*** (0.20)	-0.11 (0.44)	0.11* 2.67	2.29^{oo}
Netherlands	1972-2016	0.28*** (0.08)	0.46*** (0.16)	0.30*** 9.14	1.63^{oo}
New Zealand	1980-2016	0.48* (0.27)	0.45 (0.33)	0.13* 2.47	2.17^{oo}
Portugal	1971-2016	0.03 (0.10)	1.23*** (0.20)	0.51*** 22.70	2.38^{oo}
Spain	1979-2016	0.17*** (0.05)	0.66*** (0.21)	0.28*** 6.66	2.19^{oo}
Sweden	1967-2016	0.38*** (0.11)	0.54*** (0.21)	0.26*** 8.34	2.32^{oo}
Switzerland	1978-2016	0.25*** (0.09)	0.44*** (0.19)	0.29*** 7.25	2.09^{oo}
United Kingdom	1970-2016	0.38** (0.18)	0.18 (0.38)	0.10 2.33	2.12^{oo}
United States	1964-2016	0.33*** (0.07)	1.04*** (0.19)	0.54*** 28.87	1.41

Notes: All regressions have been run including an intercept which have never been found significantly different from 0, consistently theoretical value. Standard errors, between brackets, below estimated coefficients. Stars indicate that a coefficient is significant at 10% (*), at 5% (**), or at 1% (***). Based on the Durbin-Watson statistic, error autocorrelation is rejected at 5% (^o), or test inconclusive (^o), or not rejected (no indication).

The estimation of relation (9) is reported in Table 1 and can be summarized as follows. Over 16 country cases, the 2x16=32 estimated coefficients have the right sign (positive) with only one exception (though small and not significant). Based on the F test, the absence of country relation can be rejected in 13 cases for which the R² range between 0.15 and 0.50. This means that the model including the two factors explains a substantial part of the variability of the

annual rate of inflation. However, another half of this variability remains unexplained in the sense that it is not correlated with the two explanatory, non-stochastic, variables. Additional variables could possibly improve the explanatory power of the model, but more fundamentally what we are trying to explain is precisely an unpredictable variable: the unexpected inflation. Therefore, there is no reason to exclude that a part of the unpredicted inflation, possibly substantial; would be purely random.

Our estimations bring additional support to the Lucas supply curve, but the influence of foreign prices is also confirmed. The estimation coefficient of the output gap of equation (9) which is the slope of the Lucas supply curve (μ) turns out to be of the right sign (positive) with no exception and significant except in two cases and range, when significant, between 0.16 for Greece and 0.55 for Italy. These results are fairly consistent with the view that there exists a positive correlation between the inflation surprise and the output gap. As for the coefficient of the real exchange rate (η), our estimations indicate that fluctuations of the prices of imported products may have a non-negligible impact on domestic inflation. Estimates of this coefficient are of the right sign except for Japan and range from 0.12 to 1.23 and add uncertainty to the pace of inflation in the short run and may cause surprises that are not correlated to the domestic production. The estimated coefficients are significantly different from 0, in 9 cases out of 16.

Two alternatives have also been tried as rough check of specification adequacy. First, we have estimated the Lucas supply curve in its most common form, by regressing the inflation surprise calculated on the CPI index, only in the output gap,

$$(10) \quad (\dot{p}_t^c - \tilde{p}_t^c) = \mu(y_t - \bar{y}_t) \quad .$$

The estimation of relation (10) is reported in Table 2 in (Appendix 2) are slightly larger but close to the one obtained using specification (9) except in the case of Portugal for which the coefficient μ becomes significantly positive and of an acceptable order of magnitude. As for Ireland, this coefficient remains the same as estimated from equation (9) and non-significantly different from zero. For the 14 other countries, the coefficients range between 0.14 (Greece) and 0.48 (Italy).

We have also tried to use the GDP deflator for calculating some kind of “domestic” inflation surprise. This avoids explaining a consumer price index which includes foreign components, by a purely domestic variable: the output gap. This leads to:

$$(11) \quad (\dot{p}_t - \tilde{p}_t) = \mu(y_t - \bar{y}_t) \quad .$$

The estimation of relation (11) is reported in Table 3 in (Appendix 2). Over the 16 countries, the estimated coefficients have always the right sign (positive) with no exception. In 11 country cases, the output gap variable is significant and the coefficients range between 0.15 and 0.43. Despite less significance, the results are quite similar than former estimations, proving their robustness.

Concluding remarks.

This paper has the modest ambition to revisit the Lucas supply curve from an empirical point of view. We confirm the empirical relevance of the relation between the inflation surprise and

the output gap under the NAIRU hypothesis. We have also found evidence of the role of imported inflation in explaining inflation surprise, thus extending the logic of the Lucas supply curve. However, these results have been obtained using over-simplistic specifications on annual time series some of which are themselves estimated. This opens the scope for further investigation for which three directions are considered in priority: testing the restriction of the Lucas model, refining the dynamics of the model and estimating the two factors model on panel data.

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Appendix 1. Lucas curve with imported inflation.

The model is:

$$\begin{aligned}
 (1') \quad & \dot{w}_t - \dot{p}_t^c = -(1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) - \beta U_t + \gamma \\
 (2') \quad & \dot{p}_t = \dot{w}_t - \dot{g}_t + v(y_t - \bar{y}_t) + \delta \dot{z}_t \\
 (3) \quad & (U_t - \bar{U}_t) = -\zeta(y_t - \bar{y}_t) \\
 (6) \quad & \tilde{p}_t^c = \dot{p}_{t-1}^c . \\
 (8) \quad & \dot{p}_t^c - \dot{p}_t = (1 - \lambda)\dot{z}_t
 \end{aligned}$$

Resolution :

$$\begin{aligned}
 (1') \quad & \dot{w}_t - \dot{p}_t = \dot{p}_t^c - \dot{p}_t - (1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) - \beta U_t + \gamma \\
 (2') \quad & \dot{w}_t - \dot{p}_t = \dot{g}_t - v(y_t - \bar{y}_t) - \delta \dot{z}_t \\
 (1') = (2') \quad & \implies \dot{g}_t - v(y_t - \bar{y}_t) - \delta \dot{z}_t = \dot{p}_t^c - \dot{p}_t - (1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) - \beta U_t + \gamma \\
 \text{Using (8) we get} \quad & (1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) = -\dot{g}_t + v(y_t - \bar{y}_t) + [\delta + (1 - \lambda)]\dot{z}_t - \beta U_t + \gamma
 \end{aligned}$$

The stationary equilibrium: $\dot{p}_t^c - \tilde{p}_t^c = 0$; $y_t - \bar{y}_t = 0$; $\dot{z}_t = 0$

$$(\dot{p}_t^c - \tilde{p}_t^c) = (y_t - \bar{y}_t) = \dot{z}_t = 0$$

This implies $\bar{U}_t = (\gamma - \dot{g}_t)/\beta$ natural rate of unemployment (NRU). Thus, we get :

$$(4') \quad (1 - \theta)(\dot{p}_t^c - \tilde{p}_t^c) = v(y_t - \bar{y}_t) + [\delta + (1 - \lambda)]\dot{z}_t - \beta(U_t - \bar{U}_t)$$

Using (3) (Okun) we get:

$$(5') \quad (\dot{p}_t^c - \tilde{p}_t^c) = \mu(y_t - \bar{y}_t) + \eta(\dot{p}_t^c - \dot{p}_t) \quad \text{with} \quad \mu = \frac{\zeta\beta + v}{(1 - \theta)} \quad \text{and} \quad \eta = \frac{\delta + (1 - \lambda)}{(1 - \theta)(1 - \lambda)}$$

Finally, with (6) (NAIRU) we get the equation to be estimated

$$(9) \quad (\dot{p}_t^c - \dot{p}_{t-1}^c) = \mu(y_t - \bar{y}_t) + \eta(\dot{p}_t^c - \dot{p}_t) \quad \text{with} \quad \mu = \frac{\zeta\beta + v}{(1 - \theta)} \quad \text{and} \quad \eta = \frac{\delta + (1 - \lambda)}{(1 - \theta)(1 - \lambda)}$$

The case of the closed economy is obtained by setting $\lambda = 1$ and $\delta = 0$.

Appendix 2. Alternative specifications

Table 2 The one factor specification of the Lucas supply curve (equation (10))

Country	Sample	Output Gap	R^2	DW
Australia	1975-2016	0.33* (0.20)	0.07	2.32^{oo}
Canada	1966-2016	0.33*** (0.09)	0.22	1.97^{oo}
France	1961-2016	0.41*** (0.13)	0.16	1.85^{oo}
Germany	1966-2016	0.33*** (0.05)	0.45	1.73^{oo}
Greece	1975-2016	0.14* (0.08)	0.06	1.46 ^o
Ireland	1977-2016	0.13 (0.12)	0.03	1.66^{oo}
Italy	1963-2016	0.48*** (0.11)	0.27	1.69^{oo}
Japan	1970-2016	0.45** (0.19)	0.11	2.28^{oo}
Netherlands	1972-2016	0.23*** (0.08)	0.17	1.68^{oo}
New Zealand	1980-2016	0.46* (0.27)	0.08	2.45^{oo}
Portugal	1971-2016	0.25** (0.12)	0.10	2.41^{oo}
Spain	1979-2016	0.09* (0.05)	0.08	2.21^{oo}
Sweden	1967-2016	0.35*** (0.12)	0.16	2.54
Switzerland	1978-2016	0.26*** (0.09)	0.18	2.38^{oo}
United Kingdom	1970-2016	0.35** (0.16)	0.09	2.16^{oo}
United States	1964-2016	0.36*** (0.09)	0.26	1.88^{oo}

Notes: Same as table 1

Table 3 The domestic Lucas supply curve – equation (11)

Country	Sample	Output Gap	R^2	DW
Australia	1976-2016	0.34 (0.21)	0.06	2.61
Canada	1966-2016	0.36** (0.12)	0.16	2.23^{oo}
France	1962-2016	0.26** (0.11)	0.10	1.60 ^o
Germany	1966-2016	0.22*** (0.07)	0.15	2.40^{oo}
Greece	1975-2016	0.07 (0.08)	0.02	2.72
Ireland	1962-2016	0.09 (0.15)	0.01	2.50
Italy	1964-2016	0.43*** (0.10)	0.26	1.73^{oo}
Japan	1971-2016	0.34** (0.17)	0.08	2.45 ^o
Netherlands	1973-2016	0.15* (0.08)	0.07	2.14^{oo}
New Zealand	1981-2016	0.27 (0.24)	0.04	2.13^{oo}
Portugal	1971-2016	0.17** (0.08)	0.09	2.29^{oo}
Spain	1979-2016	0.03 (0.05)	0.01	2.05^{oo}
Sweden	1968-2016	0.24** (0.10)	0.12	2.34^{oo}
Switzerland	1979-2016	0.20** (0.10)	0.11	2.48 ^o
United Kingdom	1971-2016	0.35** (0.15)	0.11	2.16^{oo}
United States	1965-2016	0.20*** (0.05)	0.22	1.78^{oo}

Notes. Same as table 1

Appendix 3. Data

In this paper, we test the empirical relationship on Lucas supply curve on 16 developed countries among the most industrialized countries from OECD members. The countries list is: Australia, Canada, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States.

The data come from (mostly) OECD Economic Outlook No 102-November 2017 (output-gap, CPI index, GDP in value and GDP in volume). The deflator of GDP used as a proxy for the producer price is the ratio of GDP in value to GDP in volume.

Output gap data are available only from 1985 (1991 for Germany, 1989 for New Zealand and 1995 for Greece) to 2016. To complete the series, we used OECD Economic Outlook (No 73-June 2003) the largest samples possible. In some cases, like for France, we found substantial revisions of the output gap since OECD-2003 (up to 2 percentage points of GDP for the year 1985). Thus, we found preferable to complete the output series using the HP filter for the years before 1985, taking the high frequencies component proxy for the output gap like in Baghli, (2002) et al. use in a similar study.

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