PSC Discussion Papers Series

Volume 11 | Issue 1 Article 1

1-1997

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ISSN 1183-7284
ISBN 0-7714-1992-9

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<u>Discussion Paper no. 97-1</u>

January 1997

This is a first draft of a paper submitted to the International Conference on Computer Simulation and the Social Sciences, to be held in Cortona, Italy, 22-25 September 1997.

Fertility Decline: Towards a Synthetic Model

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[Draft, 9 January 1996]

Introduction

Despite the efforts of more than two generations of demographers, the field of demography lacks consensus on a unified, comprehensive theory of one of the most important modern demographic phenomena, namely, the long-term aggregate decline of fertility -- from averages of 6 to 8 births per woman during her lifetime to averages of well under 2, at least for the most developed nations. **A fortiori**, one cannot speak of validated theory.

Theoretical literature on the topic can be characterized with three words: **proliferation; incompleteness; imprecision** [Two recent critical reviews are Burch, 1995 and Van De Kaa, 1996]. There are many theories of fertility decline, often associated with one discipline or even one author. Most of them are incomplete in one way or another. For example, some of the best-developed deal only with marital fertility and thus have nothing to say about decline in overall fertility due to changing marriage patterns. Many place strong emphasis on one variable or class of variables [e.g., wealth flows, culture, diffusion, secular individualism, demand for children, fertility control, etc.] to the relative neglect of other variables or variable sets. Most are presented in loose verbal statements, in what Boland [1989] has described as 'older, more literary approaches to analysis.' It often is difficult to know precisely what a given theory asserts, or what it predicts or implies by strict logical inference. This has hampered empirical testing.

I have suggested elsewhere that an important part of the solution to the above problems will be the development of broad computer models of fertility decline, synthesizing the disparate theories referred to above.[1] Synthesis, by definition, will tend to reduce incompleteness. The use of modern computer modelling languages will facilitate more comprehensive statements, since they enable the analyst to deal with more variables and more propositions than can be dealt with rigorously using ordinary language, formal logic, even analytic mathematics. Computer modelling will promote clarity and precision, because, without unambiguous ideas and statements of relationships, models cannot be compiled and run. Finally, computer models of theories will generate determinate logical implications subject to empirical testing. The comment of Rosero-Bixby and Casterline is apt: 'Mathematical models bind theory to precise formulations, and by doing so accentuate logical inconsistencies in theories and facilitate their testing' [1993].

This paper is a first step toward a comprehensive model of fertility decline as called for above. Its core is a synthesis of the basic socio-economic theory of marital fertility due to Easterlin [1969, 1975] with the diffusion model of Rosero-Bixby and Casterline [1993]. Some obvious links of the model with the cultural and institutional theories of Lesthaege [1983 and

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[1]. A working definition of **theory** in this context is: a set of concepts and propositions, usually stated in ordinary language, that purports to explain how and why aggregate fertility decline has occurred. A **model** is a translation of a theory into mathematical or quasi-mathematical form, and its implementation using a high-level computer language such as FORTRAN, PASCAL, or C/C++, or into special-purpose software language for mathematics or systems modelling. Boland [1989] makes a useful distinction between **pure** or **abstract** models, which are representations of the underlying logic of the theory being modelled, and **applied** models, which are more concrete and explicit, designed to apply to specific real-world problems or situations [contrast a model of fertility decline in general with a model of fertility decline in India, 1900 to date].

Lesthaege and Surkyn, 1988] and of Caldwell [1976, 1982] are sketched, but these complex theories have not yet been modelled.

The next section gives brief sketches of the central theoretical ideas of the above authors, highlighting complementarities and possibilities for synthesis. Following that, a synthetic model is presented, graphically and in the difference-equation language of Professional Dynamo Plus. Illustrative output is given for Taiwan [1957-63], a case documented by Crimmins, Easterlin, Jejeebhoy, and Srinivasan [1984].

A concluding section discusses the large elements of incompleteness remaining in the model presented, and suggests directions for needed further development.

Four Theories/Models of Fertility Decline

The theoretical works of Caldwell, Easterlin, and Lesthaege are well-known. I do not try to describe them in all their richness and detail, developed over many years. What follows are thumbnail sketches, focussing on the core ideas. The key ideas of Rosero-Bixby and Casterline already are stated in model form, and so can be given quite succinctly and precisely.

According to Easterlin, marital fertility declines when couples practice effective contraception to control family size. This occurs when **motivation** to control fertility exceeds the **costs** of doing so. Motivation is a function of the **desired number of surviving children** [the number the couple would want if control of fertility were cost-free] and of the **potential number of surviving children** [the number that the couple would have in the absence of any attempt to control fertility]. The potential number of surviving children is a function of **natural marital fertility** [the number of births a couple would have if they did nothing to control fertility] and the **level of mortality** [more specifically, the probability of a child surviving from birth to adulthood]. Natural marital fertility is defined as a function of **fecundity, lactation, and fetal mortality**. Following standard microeconomics, desired family size is defined as a function of **income, prices of children** relative to other goods**, and tastes or preferences** for children relative to other goods. Easterlin assumes that the couple makes their decision early in marriage, with a view to the maximization of lifetime utility. He emphasizes that the relevant measures of several key variables [e.g., potential children, costs of fertility control, etc.] are the **subjective perceptions** of the couple, not objective reality.

The Easterlin model is relatively clear and unambiguous, partly because it inherits ideas from formal demography, reproductive biology, and microeconomics. But it is not yet a model in the sense defined in fn.1 above. Some of the functional relationships, for instance, are not fully defined. Fertility control is said to occur when motivation > costs; but it is not clear whether the strength of motivation can be defined as a simple difference between the two. Costs of fertility regulation are in some contexts proxies or operationalized as inversely related to the number of methods known. But again, no specific functional definition is given. In empirical illustrations, some of the variables, notably, desired family size are measured directly from survey data, rather than modelled as a function of income, prices, and tastes. And, by default, many subjective variables [e.g., perceived survival probabilities] are in fact measured by objective indicators.

An interesting feature of the Easterlin model is that it relates to supply of as well as demand for children. An important consequence is that **rising** fertility in the very earliest stages of development can be accommodated within his framework.

Rosero-Bixby [1993] present a dynamical model [compartment model] in which married women of reproductive age move through three different states: 1] ’**natural**,’ in which they have no interest in controlling their fertility; 2] ‘**latent**,’ in which they want to control fertility but are not doing so for whatever reason; 3] ‘**control**,’ in which they are deliberately controlling fertility. The movement from the ‘natural’ to the ‘latent’ state is governed by a constant a, defined as the ‘instant rate of **demand for birth control**.’ The movement from the ‘latent’ state to the ‘control’ state is governed by a constant b, defined as the ‘instant rate of **access to birth control**.’ Fertility is defined as a weighted average of fertility in the control state and in the non-control states. Total size of the population of married women of reproductive age is kept constant, with a factor m governing entries [aging, marriage, etc.] and exits [death, divorce, etc.] to and from the total and from each of the three states. The core model is given by a set of three differential equations, one for each state over time.

The focus of the Rosero-Bixby analysis is on interaction diffusion or contagion. Movement to the latent and control classes is governed, in addition to the factors a and b noted above, by terms reflecting social interaction between those in the control state and those in the natural state and in the latent state. These terms are respectively hN(C/T) and hL(C/T), where N and L are the sizes of the natural and latent classes, C/T the proportion in the control class, and h and ‘instant rate of adequate contacts, including both mean number of interactions and a probability of propagation per interaction’ [1993, p.158]. The behavioural assumption is that people in the natural and latent states learn motivation to control fertility and/or knowledge of how to do so through social interaction with controllers.

Rosero-Bixby also present a model for a stratified or two-sector population [e.g., rural/urban or upper-class/lower-class] with interaction diffusion **between** as well as within strata [but with no 'migration' from one strata to the other].

Although Rosero-Bixby speak of their model as a 'demand-supply' model, they do so in a sense different from Easterlin. Their reference is to demand for and supply of **fertility control**; his is to demand for and supply of **children**. It is also important to note that their definition of fertility does not allow for any increase in fertility early in a process of transition. The fertility levels of non-controllers and controllers are assumed fixed; and the proportion of controllers can only rise -- a and b are always positive.

The basic dynamic in the Caldwell model [developed largely with reference to Third World societies in Tropical Africa and Asia] is a change in the **direction of 'wealth flows'** such that money and other resources flow from the older generation to the younger rather than from the younger to the older, as under a patriarchal system. In the latter system, the patriarch or head of an extended family derives economic benefit from large numbers of children and grandchildren. From a purely economic point of view, the more children the better. The system breaks down with the import of **Western cultural ideas and ideals** of the nuclear family, and it is this **'family nucleation'** that leads to the change of direction in wealth flows, as couples devote their resources to themselves and their children rather than to the elders. The emphasis in Caldwell's scheme is on **motivation** to control fertility; thus, his ideas tie in closely with Easterlin's concept of motivation [presumably through demand for children] and with Rosero-Bixby's 'instant rate of demand for birth control.'

Although developed somewhat earlier, Caldwell's theory may be seen as a special case of Lesthaege's more general theory of **secular individualism** as a central cultural factor in fertility [and other demographic] transitions. Ideas deriving from The Enlightenment and from the French and American Revolutions lead people to favour their own individual well-being over that of collectivities [eventually including even the nuclear family], and to give up adherence to sacred traditions, both religious and political [e.g., the monarchy]. In the populations of which Caldwell writes, it is precisely cultural Westernization that leads to the weakening of deference to traditional norms centering on the patriarch, a breakdown of family piety, and to a greater focus on the nuclear family, in what might be seen as a first step toward greater individualism.

Lesthaege views his theory as a complement to economic theories, and posits complicated interrelations between the cultural and economic spheres, with culture partly exogenous and partly endogenous with respect to economic change. His is perhaps the most complex and complete of the major theories of fertility decline [besides dealing also with marriage, divorce, cohabitation, etc.], and poses a major challenge to the modeller, well beyond the scope of this paper.

A Synthetic Model

A natural blending of the central ideas of Easterlin and of Rosero-Bixby can be modelled as follows:

1] Instead of assuming an arbitrary time path for their factor a [their 'instant rate of demand for fertility control'], express it as a function of his 'motivation for fertility control.'

2] Instead of assuming an arbitrary time path for their factor b [their ‘instant rate of access to fertility control’], express it as a function of his ‘costs of fertility control.’

The correspondence of the two sets of concepts seems almost perfect.

3] Rather than assuming unchanging fertility rates for non-controllers, define fertility rates over time that are functions of ‘natural marital fertility’ as defined and estimated by Easterlin.

4] Rather than assuming unchanging fertility rates for controllers, define fertility rates over time that are functions of ‘desired number of children’ as defined and estimated by Easterlin.

In other words, Easterlin’s socio-economic theory provides a more dynamic underpinning for the Rosero-Bixby state model, driving changes in key parameters in behaviourally meaningful ways. One way of looking at the resulting blended model is that the Rosero-Bixby and Casterline state model introduces **delays** into the basic Easterlin economic model. It also yields new concepts and measures, such as the ‘KAP-gap,’ the difference between the proportion who want to control fertility and the proportion who do so.

In the model below, I have not yet introduced Rosero-Bixby and Casterline’s interaction diffusion mechanisms. In general, their addition would speed up the process of fertility decline, and would require many re-specifications of the model.

A schematic diagram is given in Figure 1. The Appendix gives the complete code for the model, written in Professional Dynamo Plus. The present model should be considered a ‘first cut,’ or perhaps only a model sketch. Considerable work is required on the specification of empirical inputs, functional forms, and parameters, especially to model Easterlin's demand for children as a function of social and economic development, and to model the inputs [either through external diffusion or through autonomous cultural development] of the cultural influences described by Lesthaege and by Caldwell.

To incorporate Caldwell's and Lesthaege's ideas, one would have to add mechanisms for external or 'point source' diffusion, bringing in Western cultural elements whose main result would be to reduce demand for children [primarily through tastes and prices for children]. In other words, their posited mechanisms would operate through the Easterlin sub-model. In the case of Lesthaege, secular individualism also would impact on the costs of fertility control, especially through the weakening of traditional taboos [Caldwell does not deny the role of fertility control techniques and costs, but his main argument does not emphasize it]. To capture the deeper aspects of the Lesthaege theory, one would have to include empirical measures of trends in real income, allowing them to affect fertility directly through microeconomic sectors of the model, but also indirectly through their feedbacks on culture and aspirations. This work lies beyond the first steps presented below.

Figure 2 graphs a comparison of modelled fertility over time compared to observed rates for Taiwanese women 35-39, as reported by Crimmins *et al*. [1984]. This shows only that the model is *plausible*, given the several *ad hoc* and arbitrary functional definitions and parameter values contained in this first version. That is, the basic logic of the model makes sense, and it can closely track actual experience for a limited experimental case.

Discussion

Even with the extensions, additions, and refinements mentioned above, the current model will remain limited -- a model of marital fertility, in isolation from broader demographic dynamics. It does not deal with changing marriage patterns, for example, a potentially serious omission given the common view that in the early stages of fertility transitions, control of marital fertility and delayed marriage are partial substitute behaviours. An isolated model of marital fertility also will not include the impact of broader demographic dynamics relating to population size, growth, and density, and the role of out-migration in relieving 'population pressure.' This is of concern when one realizes that in the middle stages of demographic transition, population size [and thus density] can easily double in well under 30 years [at growth rates of 2.5 to 3%], that is, in a period shorter than a reproductive generation. Feedback effects on fertility behaviour seem likely. A doubling of density would seem particularly relevant to a model incorporating Rosero-Bixby and Casterline's interaction diffusion mechanisms, since 'contagion' would tend to rise with density, and also with migratory movement associated with population increase in local areas [notably, urban-rural migration], as well as with literacy, communications infrastructure, etc.

How far should the current model be extended? A common axiom in the modelling literature is that every model must be constructed for a specific purpose, and judgements as to a model's success must depend on its purpose. My current aim is to try to achieve greater unity and rigour in our theoretical statements about fertility decline -- modelling is being used primarily as a tool for theoretical development -- to arrive at theoretical statements that seem better to capture the dynamic complexity of real world processes than some earlier formulations. From this perspective, the present model can only be a first step; the extensions sketched above need to be incorporated. The resulting models should be useful for scientific purposes of explanation and prediction, and in variant forms, should lead to effective empirical testing of conflicting theoretical ideas [see Cleland and Wilson, 1987, on ideational versus economic explanations of fertility decline].

For policy and program purposes, extensions are needed, but in different directions -- to add details on the role of government laws and policies [e.g., China's one-child policy], and on the nature and strength of family planning programs.

Eventually there will be many different models of fertility and fertility decline, but one hopes they will all share a common behavioural scientific core of validated theory, similar to what has been presented above.

This paper is presented as a small first step towards 21st century analysis -- away from relatively simple, static, linear models and from purely verbal conceptual/theoretical formulations, towards computer models that are complex and dynamic, and stated with greater clarity and precision.

* * *

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Appendix: Professional Dynamo Plus code

*** Synthesis of Easterlin and Rosero-Bixby/Casterline [30 Dec. 1996]**
*** Data for Taiwan, 1957-73**

*** The Easterlin Model**

*** Empirical Data**:

```
*  Survival rates as function of time
A   surv.k=tabhl(tsurv,time.k,0,16,4)
T   tsurv=0.843,0.879,0.901,0.939,0.977
```

```
*  Desired family size as function of time
A   cd.k=tabhl(tcd,time.k,0,16,4)
T   tcd=4.4,4.37,4.28,3.97,3.66

*  Natural fertility as function of time
A   n.k=tabhl(tn,time.k,0,16,4)
T   tn=5.55,5.86,6.27,6.29,6.31

*  Number of methods known by time
A   meth.k=tabhl(tmeth,time.k,0,16,4)
T   tmeth=2.7,3.14,3.7,4.95,6.2 Note: first value estimated from '<3.0'

*  Observed fertility by time
A  bo.k=tabhl(tbo,time.k,0,16,4)
T  tbo=5.46,5.6,5.56,4.97,4.38

*  Chesnais series
A  tfr.k=tabhl(ttfr,time.k,0,16,4)
T  ttfr=6.0,5.6,4.8,4.1,3.2

*  Observed surviving children by time
A  co.k=tabhl(tco,time.k,0,16,4)
T  tco=4.6,4.898,5.01,4.56,4.11
```

*** The model**

```
*  Potential family size
A  cn.k=n.k*surv.k

*  Costs of fertility control
A  cost.k=1/meth.k

*  Motivation to control fertility
A  mot.k=cn.k-cd.k

*  Net motivation or births averted; motivation minus costs or zero
A  nmot.k=max(mot.k-cost.k,0)

*  Fertility: natural fertility minus births averted
A  b.k=n.k-(nmot.k/surv.k)

*  Simulated surviving children
A  c.k=b.k*surv.k
```

* Zero for graphs

A dummy.k=0

*** The Rosero-Bixby/Casterline Model**

*** Initial values**

```
C  it=1
N  total=it
C  ic=0.176
N  contra=ic
C  il=0.203
N  latent=il
C  in=0.620
N  natural=in
```

*** Core Equations**

```
L  natural.k=natural.j+dt*(m*total.j-m*natural.j-proba.jk*natural.j)

L  latent.k=latent.j+dt*(proba.jk*natural.j-m*latent.j-probb.jk*latent.j)

L  contra.k=contra.j+dt*(probb.jk*latent.j-m*contra.j)

A  total.k=natural.k+latent.k+contra.k
```

*** Summary indicators**

```
A  y.k=contra.k/total.k
A  kg.k=latent.k/(latent.k+contra.k)

A  nocontf.k=(1/m)*(n.k/5.55)*0.31
A  contf.k=(1/m)*(cd.k/4.4)*0.08
A  f.k=(nocontf.k*(1-y.k)+contf.k*y.k)
```

*** Parameter values**

P m=0.05

A aprob.k=mot.k/6.5
R proba.kl=aprob.k

A bprob.k=1/(45*cost.k)
R probb.kl=bprob.k

*** Absolute and relative erors in simulated fertility**

A diff1.k=b.k-bo.k
A relerr1.k=diff1.k/bo.k

A diff2.k=f.k-bo.k
A relerr2.k=diff2.k/bo.k

Control Statements

SAVE surv,n,mot,cost,nmot,b,bo,co,c,cd,cn,dummy,y,kg,f,diff1,diff2,^
relerr2,relerr1,total,natural,latent,contra,probb,proba,tfr,contf,nocontf
SPEC dt=0.125/length=16/savper=1

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