Chapter 12
Explaining the Explanations of 100 Million Missing Women

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Abstract This chapter studies the methodology in the missing-women debate among economists and biologists. One of the central philosophical and methodological issues at stake in the missing-women debate is natural and social scientists' attempts for discovering the underlying causal structures and mechanisms. Although they encounter the same problem of inferring the mechanism and causal structure in face of available data, the discovering strategies vary. In this chapter, we will comparatively study the strategies of discovering causes and mechanisms in the case of missing women.

1 Amartya Sen's Missing Women

Nobel laureate economist Amartya Sen opened his 1990 *New York Review of Books* article, "More Than 100 Million Women Are Missing," with the following sentences:

> It is often said that women make up a majority of the world's population. They do not. This mistaken belief is based on generalizing from the contemporary situation in Europe and North America, where the ratio of women to men is typically around 1.05 or 1.06, or higher. In South Asia, West Asia, and China, the ratio of women to men can be as low as 0.94, or even lower, and it varies widely elsewhere in Asia, in Africa, and in Latin America. How can we understand and explain these differences, and react to them?

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Sen referred to the observations of exceptionally low female-male population ratios in certain Asian countries compared with those in Western countries. Recently, this issue has been referred to in the literature as the "missing-women" problem. It is a problem, as Sen sees it, because the observations reveal an abnormality. The normal circumstance would consist of the following elements. At the outset, the laws of nature suggest that the number of male births is higher than female births; therefore, the men-women sex ratio at birth should be higher than unity.[1] But the mortality of males is also higher than that of females, a fact that is thought to be compensated for by the higher male birth rate—a natural "regulatory mechanism" that should result in an actual men-women ratio of unity (Chahnazarian 1988, p. 217). This suggests what the observed sex ratio should be if biological factors were the only ones to affect human reproduction.

However, for Sen, the *natural laws* are conditional on gender equality; that is, they are conditional on whether men and women receive similar nutritional and medical attention and health care. Consequently, when the observed sex ratio deviates from that which biology would indicate in such a way as to favor the number of men, then there are missing women, and that calls for explanations and calculations. Moreover, such a deviation should be attributed to the unequal social and cultural treatment of women. Sen argues that these sociocultural causes could be expressed in the single composite factor of *son preference*, meaning the parental preference for boys over girls. Sen subsequently concludes that there are 100 million women missing due to the prevalence of son preference in the non-Western countries—50 million in China alone.

There are some methodological issues concerning Sen's assertion. On the one hand, there is the question of exactly how many women are missing; on the other hand, there is the question of the cause of this phenomenon. The answers to these questions are dependent on each other. To calculate the number of missing women, we must determine the numbers of males and females in an entire population to calculate the sex ratio, which in turn is affected by factors that cause either low birthrates, high mortality rates, or shortened life expectancy of females. Sen thus provides a possible explanation for the way the factors categorized as son preference result in missing women.

Sen's study reflects the long-standing issue of the human sex ratio, which has been studied since the seventeenth century, when statistical data were first collected. For example, John Graunt (1662) and John Arbuthnot (1710) statistically analyzed the English data and showed that the high male-female sex ratio at birth (around 105 boys per 100 girls) was not due to chance (Hacking 2006). Evolutionary theories of sex ratio were developed in the nineteenth century (Sober 2007). These studies provide the foundation for the *normal*, or *natural*, state, in which nonnatural factors do not intervene with the sex ratio at birth.

[1] Sex ratio at birth is also called *offspring sex ratio*. Throughout this chapter, the sex ratio is defined as the number of men per women.

Based on this work, social scientists conducted research on the socioeconomic mechanism behind and the causes of the missing women. In Chahnazarian's (1988) extensive review of the biological and sociodemographic determinants of the sex ratio at birth, the latter includes factors such as maternal age, paternal age, and birth order. In addition, economists have investigated the explanatory power of economic factors such as income and wage. They go even further to study whether and how son preference is affected by such factors. Sen, for instance, implied that the anomalous sex ratio may have been caused, and might be cured, by the economic factor "gainful employment," defined as the condition of having paid work outside the household. Women's gainful employment may have an effect on other factors—such as son preference and women's inequality—and in turn on the sex ratio.[2] Hence, Sen urges policy interventions, such as providing better education for women, as a cure.

In this chapter, we review the debate about the cause of the missing-women phenomenon—that is, the debate about whether the phenomenon is caused by biological or cultural determinants. Our purpose is to show a crucial role that the conception of causal structure plays in explaining or explaining away the supposed observation of missing women. It is also argued that the complementary strategy has been adopted to form a relatively more complete causal structure that can be used to tell a relatively more complete causal story about the underlying mechanism that is thought to be responsible for the occurrence of Asian countries' missing women.

2 How Baruch Blumberg Explains His "Strangest Observation"

In biomedical science, researchers attempted to seek different explanations for the missing women. One example is Baruch S. Blumberg, the 1976 Nobel laureate in medicine. Blumberg's research focuses on the hepatitis B virus (HBV), which he discovered in 1965. He observed during his fieldwork in Greece possible associations between HBV infection and sex ratio (Hesser et al. 1975). He later found similar results in the countries having high HBV prevalence, such as Greenland, Kar Kar Island, and the Philippines.[3] Specifically, Blumberg found that "carrier" families, that is, either parent was a chronic carrier who is a person who tests positive for hepatitis B surface antigen (HBsAg) but does not develop an antibody against HBsAg (anti-HBs), had a higher sex ratio (i.e., more boys) than did the families that had no evidence of HBV infection. In contrast, the "antibody"

[2] See Qian (2008) for an empirical study of the relation between women's gainful employment and sex ratios.

[3] Oster (2005, Table 3) summarizes the original data of these micro-studies of offspring sex ratio by parental HBV infection.

families (either parent had anti-HBs) had the lowest sex ratio. Moreover, Blumberg found that HBV carrier mothers have fewer female births and consequently conjectured that HBV may cause a high sex ratio at birth.

The observation of the relation between the response of a parent to infection with HBV and the gender of his or her offspring is Blumberg's "strangest" one, because it means that HBV is gender biased (Blumberg 2002, p. 182). In a sense, there is biological evidence supporting Blumberg's observation. Before Blumberg proposed his hypothesis, scientists had already known that HBV infections are gender sensitive. For instance, males are more likely than females to become HBV carriers, that is, more likely to be HBsAg(+), whereas more females than males develop anti-HBs. As a result, Blumberg thought that he had provided a "biological explanation" for the issue of the missing women, an issue he had learned about from a prominent demographist, Ansley J. Coale:

> [Coale] published a paper concerning the high sex ratios that have been observed in China. He proposed that, because there is no other biological explanation, the apparent deficit in female births in China could be a consequence of female infanticide. As might be expected, his findings and conjectures had a big play in the media. I pointed out to him that there might be a biological explanation. China, and particularly South China, has some of the highest frequencies of HBV carriers in the world. If our observations on the relation between carriers and gender of offspring in Greece and elsewhere were also valid in China, then this might provide a biological explanation for apparent loss of female children. (Blumberg 2002, p. 185)

Carrier families are more likely than antibody families to have male children. Consider the countries where the incidence of both HBV and son preference is high. If families would like to have children until they reach the desired number of boys, then antibody families, who are more likely to have girls, would have a lower sex ratio and a larger family size than carrier families. The hepatitis B hypothesis hints at one intriguing policy implication: if an HBV vaccination program were successful, then there would be fewer carriers and hence a lower sex ratio at birth, with the consequent effect on family size and the sex ratio of the population.

Drew et al. (1978) first offered a theory on the way HBV affects sex ratio. Based on the facts that males are more likely to be HBsAg(+) and females are more likely to be anti-HBs(+) and the statistical facts that parents with HBsAg(+) have a higher sex ratio (more boys) and parents with anti-HBs(+) have lower sex ratio (more girls), Drew et al. (1978, p. 691) conjecture that males would recognize HBsAg as "self" and remain HBsAg(+) persistently (i.e., become carriers). By contrast, females would be more likely to recognize HBsAg as "foreign" and thus produce anti-HBs. Hence, HBsAg(+) is associated with the possibility of giving birth to more boys, and anti-HB(+) is associated with giving birth to more girls. Drew et al. (p. 691) provided some possible explanations: either HBsAg protects male fetuses or anti-HBs hinders fertilization by a Y-bearing sperm. But the proposed mechanism is still a conjecture, as Blumberg recently admitted that there is no evidence for such effects of HBV in utero (2007, p. 229).

3 How Economists Explain 100 Million Missing Women

Blumberg's hepatitis B hypothesis is interesting, but no economist took it seriously until Emily Oster's (2005) article was published. Oster tested Blumberg's idea on a population level using both time-series and cross-sectional data. In particular, Oster used the historical data of Taiwan's universal vaccination of all newborns beginning in 1984 to conduct an empirical test to see whether there is indeed a significant positive correlation between the variable of HBV prevalence and an increase in the sex ratio at birth. Taiwan's vaccination case forms a natural experiment that is ideal for testing the correlation, because economists can analyze the historical data of births to vaccinated and unvaccinated mothers to see whether there is a great gap in offspring sex ratio between these two groups; if there is indeed a significant difference in sex ratio at birth, then HBV has a positive effect on the percentage of children who are male; otherwise, it does not.

Although Oster's testing result showed that there is a significant correlation between HBV prevalence and sex ratio at birth, she noted a caveat to her conclusion. Oster observed that Taiwan's vaccination program coincided quite closely with an increased availability of fetal sex-determination technology and a probable increase in sex-selective abortion. Consequently, the magnitude of the difference in sex ratio at birth between vaccinated and unvaccinated mothers is likely to be smaller than it otherwise would be, because the effect of vaccination on decreasing sex ratio at birth is offset by the countervailing behavior of adopting fetal sex-determination technology, which was motivated by the cultural cause of son preference.

However, in a cross-country analysis, Oster, by applying the least-square method on single equations, found a significant correlation between HBV and sex ratio at birth. She also stated that about 75 % of Sen's 100 million missing women could be explained by parental infection with HBV, implying that son preference plays a lesser role in explaining the missing women. Soon after, Blumberg (2006a, b) characterized Oster's finding as one of the great achievements of HBV research, because it supported his previous findings and confirmed that HBV does have effects on gender.

In response to Oster's biological explanation, Monica Das Gupta, a supporter of the cultural explanation, maintained that the Chinese sex ratio at birth for the first birth was always within the normal range of 1.05–1.06. A higher sex ratio at birth was observed only in subsequent births. In addition to these two empirical testing results, Das Gupta found that an extremely high sex ratio at birth was observed mainly among women who had previously given birth only to daughters. Together, these results strongly suggest that it is son preference, rather than HBV, that has the significant effect on distorting sex ratio at birth and therefore it is the former, rather than the latter, that is the cause of the missing women (Das Gupta 2005, 2006). In response, Oster (2006) pointed out that she does not disagree with the cultural explanation; rather, she opposes Das Gupta's position that "the support for cultural explanations allows to conclude that the biological explanation is not particularly

salient" (Oster 2006, p. 324). To reconcile her biological explanation with the cultural one, Oster, with her coauthor, proposed a further hypothesis: it is possible that HBV interacts in a complicated way with birth order and the sex of previous children (Oster et al. 2008).

Against this background, a pair of Taiwanese economists—Ming-Jen Lin and Ming-Ching Luoh—conducted a study that was designed mainly to test whether Oster's further hypothesis is sustainable (Lin and Luoh 2008). They acquired a unique dataset of Taiwan's nationwide hepatitis B vaccination program that was launched in July 1984. The data, more substantial than Oster's Taiwanese data in size, are the comprehensive historical data obtained from the Hepatitis B Mass Immunization national databank of Taiwan, which includes gender, year and month of birth, birthplace, mother's age, birth order of the child, unique ID of the mother, and mother's HBV status at the time of pregnancy. Lin and Luoh conducted a regression analysis to see whether there was any significant correlation among gender, birth order of the child, and mother's HBV status. The specification of their regression is as follows:

$$\begin{aligned}\text{Boy} = \alpha &+ \beta_1\ \text{HBsAg} \\ &+ \beta_2\ (\text{Birth Order 2}) \\ &+ \beta_3\ (\text{Birth Order 3 and higher}) \\ &+ \beta_4\ \text{HBsAg} \times (\text{Birth Order 2}) \\ &+ \beta_5\ \text{HBsAg} \times (\text{Birth Order 3 and higher}) \\ &+ \beta_6\ (\text{Mother Age Dummies}) \\ &+ \beta_7\ (\text{Child Birth Year Dummies}) \\ &+ \beta_8\ (\text{Birth Township Dummies}) \\ &+ \varepsilon \end{aligned} \tag{12.1}$$

Parameter β_1 measures the effect of HBV on sex ratio at birth; parameters β_4 and β_5 investigate whether the effect of HBV differs among different birth orders. Lin and Luoh's argument appeals to both substantive and statistical significance. If the testing results are that the estimated value of β_1 is small and statistically insignificant and if there is no significant difference between β_4 and β_5, it then suggests not only that HBV plays no role in determining sex ratio at birth but also that some part of the further hypothesis—that is, the hypothesis that there are complex biological mechanisms in operation between HBV and birth order—should be ruled out. On the other hand, the magnitude of the values of β_2 and β_3 indicates whether the offspring in higher birth orders are more likely to be male; if the magnitudes are large enough to be significant, then the result supports the son-preference explanation. The end result of Lin and Luoh's testing is that β_1 is small and sometimes insignificant; measuring the effect of HBV on sex ratio at birth, parameters β_4 and β_5 are small and insignificant, confirming that birth order does not amplify the effect of HBV. Together, these two results show that the biological explanation is

not sustainable. As for β_2 and β_3, the value of β_2 is small and insignificant, and β_3 is very large and significant; these results together indicate that variation in the sex ratio at birth mainly affects third and later children and thus suggests that the cultural explanation is more plausible.

To test the other part of the further hypothesis—that the effect of HBV varies with the sex of previous children—Lin and Luoh ran another regression as follows:

$$\begin{aligned}\text{Boy} = \alpha &+ \beta_1 \text{ HBsAg} \\ &+ \beta_2 \text{ (First two children are girls)} \\ &+ \beta_3 \text{ HBsAg} \times \text{(First two children are girls)} \\ &+ \beta_4 \text{ (Mother Age Dummies)} \\ &+ \beta_5 \text{ (Child Birth Year Dummies)} \\ &+ \beta_6 \text{ (Birth Township Dummies)} \\ &+ \varepsilon \end{aligned} \tag{12.2}$$

Again, following the same logic of identifying whether the effect of HBV varies with birth order, Lin and Luoh checked whether the values of β_1 and β_4 were large and significant; if they were, the result would indicate both that HBV indeed plays an important role in determining the offspring sex ratio and that there is indeed some interaction between HBV and the sex of the first two children. According to Lin and Luoh's result, both β_1 and β_3 are small and insignificant, but β_2 is very large and significant. This result thus also suggests that the son-preference explanation is more plausible. So this allows the authors to rule out the "complex biological mechanisms" of HBV inflections on the sex ratio (Lin and Luoh 2008, p. 2264).

Oster soon struck back. She teamed up with Blumberg (Blumberg and Oster 2007). They argue that, empirically, paternal, not maternal, hepatitis carrier status is more strongly correlated with sex ratio at birth. Yet their 13-page manuscript was never completed and published. Perhaps Oster found that the hypothesis was not sustained; her recent 2010 paper, written with three Chinese medical officials and researchers (Oster et al. 2010), claims that by analyzing the data of Haimen City in Jiangsu Province, China (sample size = 67,511 individuals), no relationship between paternal HBV and the missing women is found. Consequently, she conceded that HBV cannot explain the missing women in Asia.

4 Difference in Methodology

The case of missing-women debate can be seen as an example of *extrapolation* in the sense of Daniel Steel (2008; see also Steel's chapter in this volume, 2013). Researchers compare the target with the sources originating from other disciplines and geographic regions and draw similarities that could serve as a guide for further investigation. Where the strategy of discovering the missing women is concerned,

we notice methodological similarities and dissimilarities among economists and biomedical scientists. First, we find that Sen's and Blumberg's theorization processes may best be understood in terms of *Inference to the Best Explanation* formulated by, inter alia, Peter Lipton. Lipton's Inference to the Best Explanation has a root of Charles Sanders Peirce's *abduction*, which consists the form of inference: "The surprising fact, C, is observed; but if A were true, C would be a matter of course, hence, there is reason to suspect that A is true." Inference to the Best Explanation stresses also on inductive inference. Lipton maintains that scientists infer from available evidence to the hypothesis that would provide the best explanation for that evidence. For instance, as Lipton states, Darwin inferred from his biological evidence the theory of natural selection because natural selection would best explain that evidence (Lipton 2000, p. 184). Conversely, inference is guided by explanatory considerations, particularly by those explanations that provide most understanding if true—the *loveliest* explanations.[4] This seemingly circular argument in fact describes well how a hypothesis is formulated in science, how it is justified as the best hypothesis among many competing hypotheses, and how it can heuristically guide the inference process. It is also stressed that Inference to the Best Explanation is fallible. Because all available evidence does not necessarily lead to truth, the best explanation may not be the actual explanation. Lipton's reconstruction of Carl Hempel's (1966) discussion of Ignaz Semmelweis's attempt to explain different rates of childbed fever in two hospital wards well demonstrates how the best explanation to such observation can be derived from the account of Inference to the Best Explanation (Lipton 2005).

It seems both of Sen's and Blumberg's studies fit well the account of Inference to the Best Explanation. In our case study, Sen and Blumberg seek to infer from evidence the best explanations for Asia's missing women. Sen derives missing-women phenomenon from the sex ratios in Asia from those in the Western countries, and then he infers from the evidence that the son preference induced by women's gainful employment is the best explanation for Asia's missing women. Similarly, Blumberg infers from his data that the hepatitis B hypothesis is the best biological explanation for the missing women, in which he uses his knowledge of the hepatitis virus, especially the feature of gender sensitivity. Despite the fact that both Sen's cultural hypothesis and Blumberg's hepatitis B hypothesis provide the best explanation for their evidence, we observe that the consideration of explaining the missing-women phenomenon has been the guiding force to direct them to adopt a particular inference strategy for carefully developing their accounts by explaining and explaining away the adequacy of explanatory components. So doing makes their explanation better than others. Yet it would still be understandable should Sen's and Blumberg's hypotheses have turned out to be false explanations in the face of newly acquired data, and have been replaced by a theory providing better account for the data.

[4] By contrast, a likeliest explanation is the explanation that is best warranted by the evidence.

Contrasting with Sen's and Blumberg's attempts to theorize the missing-women phenomenon, Oster's and Lin and Luoh's studies are conducted by running regressions on data to find significant statistical relations between high sex ratio at birth and factors that might influence it. Although they intend to find the causal power of the factors, it is not obvious whether they are concerned with finding the true causal relationships. For instance, Oster (2005, p. 1164) stated that "after one adjusts for differences in the sex ratio at birth *caused* by hepatitis B, the number of missing women (based on population estimates from 1980 to 1990) drops to 32 million" (our emphasis), but she has been cautious in using causal language in other places. In Blumberg and Oster (2007), she used correlation ("paternal, not maternal, infection is correlated with higher offspring sex ratios") more often than causation. Oster is concerned only to justify the hepatitis B hypothesis by claiming that the causal relation is supported by relevant correlations. Similarly, although Lin and Luoh found that cultural factors are causal to the missing women and they claimed that the biological mechanism is ruled out, they could not, or would not, find the true causal mechanism.

We might use Trygve Haavelmo's (1944) famous mechanical analogy to illustrate. We could derive the functional relation between the pressure on the throttle and the speed of a car on a flat road under usual conditions, but such a relation will break down as soon as there is a change in any working part of this car, or a change in an external condition. The throttle-speed relation is less *autonomous* because this type of relation is not invariant to changes in the surrounding conditions and thus is not fundamental to economics. For Haavelmo, the general laws of thermodynamics and the dynamics of friction are examples of highly autonomy relations, because they "describe the functioning of some parts of the mechanism irrespective of what happens to some other parts" (Haavelmo 1944, p. 28). The real automobile mechanism is hard to be discovered without opening the hood, one might still be able to find out what causes the throttle/speed relationship to break down. The econometric studies of Oster and of Lin and Luoh focus on economic relations such as the one between throttle pressure and speed; they are interested in whether or not certain relations sustain, rather than opening the hood and seeing the engine of the car. They intend to find factors that causally relate to sex ratio at birth, empirically speaking, and use the empirical finding to vindicate or repudiate hypotheses.

5 Causal Structure and Net Result

Given Lin and Luoh's empirical result that the effect of hepatitis B on an increase in the sex ratio at birth is limited, we might conclude that economists are no longer willing to endorse the idea that hepatitis B has the efficiency to affect the sex ratio.

This description seems to be further justified by Oster's remarks about the idea of science:

> I'd be lying if I told you it wouldn't be great if I was right all the time. . .If you work like this, especially if it's something that people care about, and you get to collect some more data that is maybe going to be even more informative than what you had before, it's your responsibility to do that. This is the way science works.[5]

On the face of it, Oster's statement might be regarded as representing two methodological points. One is the doctrine that follows the tradition of Popperian falsificationism; the other is that the size of data does matter. The aim of science, including economics, is to identify stable connections—or *regularity laws*—among variables (or factors) of interest so that, by using these connections or laws, scientists are able to explain the phenomena that are thought to be governed by the connections or laws. If, in the process of hypothesis testing, the scientists somehow find out that there are no stable connections or lawlike relations among the targeted variables, the correct action is for scientists to repudiate their hypotheses about those connections or laws. In our case, the hepatitis B hypothesis is that there is a positive connection between the prevalence of hepatitis B among mothers of newborns and the increased ratio of newborn males to females and thus the number of missing women. In her 2005 paper, Oster, by using various quantitative strategies and a larger dataset than Blumberg's, concluded that there is indeed a robust connection between hepatitis B and the missing women, so she suggested that hepatitis B could explain the phenomenon. Later, Lin and Luoh's study of three million newborns rejected the hepatitis B hypothesis. In order to respond to Lin and Luoh, Oster et al. (2010) used new empirical data and found no effect of hepatitis B carrier status on the sex ratio. This finding led her to reject the hepatitis B hypothesis and claim that hepatitis B does not explain male-biased sex ratios in China. Oster's practice of rejecting her previous hypothesis thus illustrates that her action following her doctrine of science.

However, if we interpret the missing-women debate in this methodological sense, then the following short paragraph, which is quoted from the 2008 working paper version of Oster et al. (2010), may seem puzzling (Oster et al. 2008, p. 6):

> [After showing] that hepatitis B carrier rates cannot explain male-biased sex ratios or the 'missing women' in China . . . [a]n important remaining issue is whether it is possible to reconcile the biological results in the original paper (Oster 2005) with these [2008] results and, in particular, how the individual-level data from outside of China and the evidence from vaccination campaigns in Alaska can coexist with new results from China . . . We revisit the original individual-level data from Greece and the Philippines and continue to find support for the connection between *paternal* hepatitis B carrier status and offspring sex ratio. Moreover, in the data from China discussed here, we also find some interaction between hepatitis B, gender and fertility: women with the hepatitis B *e* antigen (carriers who are also replicating an additional viral antigen) seem to have fewer male children. Further, women who are carriers of the virus have fewer children overall, even with extensive controls. Together, this evidence suggests that there may still be some interaction between hepatitis B and fertility outcomes (in general) but that clearly the pathways are much more complicated than the simple carrier-male offspring connection.

[5] Quoted in Justin Lahart, "Economist Scraps Hepatitis Theory on China's 'Missing Women,'" *The Wall Street Journal*, May 22, 2008.

If we read between the lines, the quotation seems to suggest that even though the new empirical result does not support the hepatitis B hypothesis, the hepatitis hypothesis should not be rejected immediately; economists would rather at one stage hang on to the refuted hypothesis and try to find a way to reconcile the old findings with the new ones. In this sense, we might define two methodological views of science. On the one hand, science is traditionally regarded as being constituted by a great number of theories. The aim of each theory is to provide an explanation for a phenomenon in question. Each theory in turn contains a number of hypotheses, each of which posits a general law that is supposed to govern or regulate a corresponding part of the targeted phenomenon if that part can be logically derived from the general law. Once all the relevant hypotheses—that is, the relevant regularity laws—of the theory can be used to derive the corresponding parts of the phenomenon, the theory is said to provide an explanation of the phenomenon. When a new phenomenon of a similar kind can no longer be derived from—or explained by—the same theory (the same set of regularity laws), then the theory and its component laws should be *substituted* or *replaced* by other new theories and their component new laws. We may call the idea that involves the description of scientists' practices the *substitutive* conception of scientific practices. This is Popperian in spirit.

On the other hand, our case study shows that the substitutive framework does not necessarily appear in economists' practices. The empirical result of Lin and Luoh is thought to reject the hepatitis B hypothesis by their findings of little effect of HBV on the sex ratio at birth and a significant correlation between higher birth order and the sex ratio at birth. Yet we also witness the so-called *complementary* conception of scientific practice as followed in Oster's work: when scientists want to check whether there is a significant correlation between any two targeted events, they usually apply empirical tools, such as regression analysis, to run a significance test. When they find that the estimate that represents the correlation does indeed fall within the prescribed confidence interval, they accept the correlation hypothesis and confirm that there is a correlation between the two events. In contrast, if the estimate falls outside the confidence interval, it is normally presumed that such a hypothesis should be rejected and no correlation is acknowledged. Yet in practice it is intended to append additional conditions to the failed hypothesis to explain why the hypothesis conflicts with the testing result. In other words, some explanation is provided to reconcile what is stated in the hypothesis and the contradictory testing result. In fact, Oster herself used the term complementary that fits precisely into our observation. In her reply to Das Gupta's comments, Oster stated (Oster 2006, pp. 325–326),

> The key to thinking about the relative potential of culture and biology to explain the over-representation of men in a population is understanding that marginal effects may be seen to operate and still tell us relatively little about the average. In the end, it seems better to think of these two explanations as *complementary*. The issue of gender imbalance in Asia—the causes and consequences—is an important one; we should endeavor to have a *complete* understanding, not just a partial one. (our emphasis)

In order to have a complete understanding, it needs first to understand the fact that the observed correlation between any two targeted events is in fact the *net result* of a complicated interaction among a great many relevant factors involved in

the two events. Based on this supposition, thinking in terms of causal structure is helpful. Hypothesis testing is conducted under an overarching assumption that the relevant factors interact with each other to form a *causal structure*, defined by Nancy Cartwright as "a fixed (enough) arrangement of components with stable (enough) capacities that can give rise to the kind of regular behavior that we describe in our scientific laws." Cartwright (1997, p. 343) explains that "capacity is used to mark out abstract facts about economic factors: what they would produce if unimpeded" (Cartwright 1998, p. 45). According to the idea of causal structure, it may seem that what is supposed to be stable are the capacities (or causal powers) possessed by those member factors of the structure. However, the regular association of the targeted factors that is described in the regularity law is generated from a causal structure, and therefore the stability of the association—that is, the degree to which the law is regular—depends on whether the causal structure itself is in a stable condition. If, however, an unexpected new factor intrudes into the original layout of the structure, this new factor will destroy the original stable condition of the causal structure and therefore bring about a new equilibrium state that is not consistent with what is stated in the original regularity law. From this perspective, Cartwright argues that, contrary to the general belief that regularity laws are necessary regular associations that regulate or govern any two targeted factors, "[regularity] laws are transitory [or contingent] and epiphenomenal, not eternal"; the stability of regularity laws is subject to whether the causal structure is capable of repeatedly generating them (Cartwright 1999, p. 122).

Based on this structural thinking, it may seem that a regularity law should be repudiated when the result of hypothesis testing tells us to do so. But we shouldn't throw out the baby with the bath water; we shouldn't throw out the causal factors with the defective regularity laws, but rather should attribute the failure of their hypothesis to the instability of the causal structure rather than to the causal factors, which possess stable capacities or causal powers. Whenever there is an anomalous phenomenon that is inconsistent with their hypothesis about a regular correlation between two factors, we can still consult the old knowledge of the capacities of the relevant factors and then *imagine* a new causal structure from which, by using these two pieces of information, a new regularity law can be derived. The new regularity law can in turn be used to explain why and how the previously unexplainable phenomenon occurs. The old knowledge of capacities is in this sense complementary to the knowledge of the new causal structure and regularity law. We may then call this description of economists' practices the complementary conception of scientific practices.

6 Strategies for Discovering Asia's Missing Women: Causal Structures

Let's again use the case of missing women to illustrate how economists develop complementary scientific practices. The hepatitis B hypothesis states that HBV has a positive effect on sex ratio at birth (SRB). This simple causal structure is illustrated in Fig. 12.1.

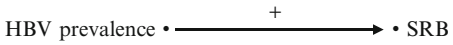

Fig. 12.1 The simple causal structure of hepatitis B hypothesis

where the symbol "+" indicates positive effect.

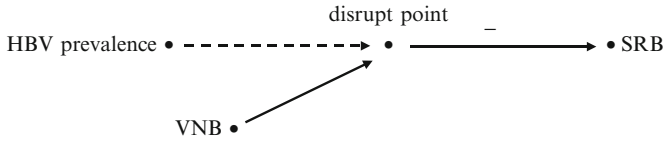

Fig. 12.2 The biological causal path being disrupted by vaccination campaign

where the symbol "−" denotes negative effect; the dotted line denotes the disruption of the original effect.

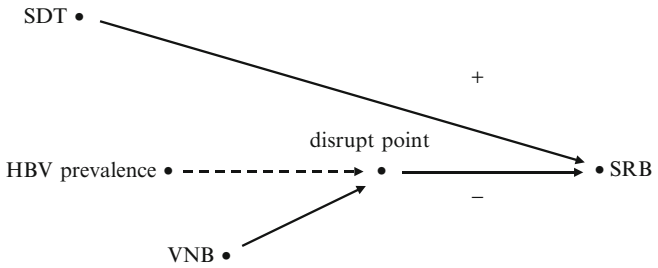

Fig. 12.3 The relatively more complicated causal structure with the further causal influence of SDT

Figure 12.2 illustrates that, because of the introduction of a universal vaccination program for newborns (VNB), the original causal path is disrupted by the intrusion of VNB, and the figure also shows that VNB has the negative effect of reducing SRB.

Figure 12.3 shows that, by further considering that Taiwan's universal vaccination program was launched about the same time as the use of fetal sex-determination technology (SDT) became prevalent, the original causal structure should be supplemented with an additional causal path leading from SDT to SRB; the figure shows that SDT has the positive effect of increasing SRB.

In Fig. 12.3, there are two competing causal paths that jointly determine the degree of SRB, and the entire causal structure represented in Fig. 12.3 also reflects the concern that, because of the introduction of SDT, the magnitude of VNB's effect on reducing SRB is likely to be offset by the new effect of SDT, which has a positive effect of increasing SRB to a certain degree.

It is mentioned in Oster (2005, p. 1185) that this offsetting effect would be mitigated if a large portion of the population were indifferent to whether they have sons or daughters. With the addition of this further concern, the causal structure

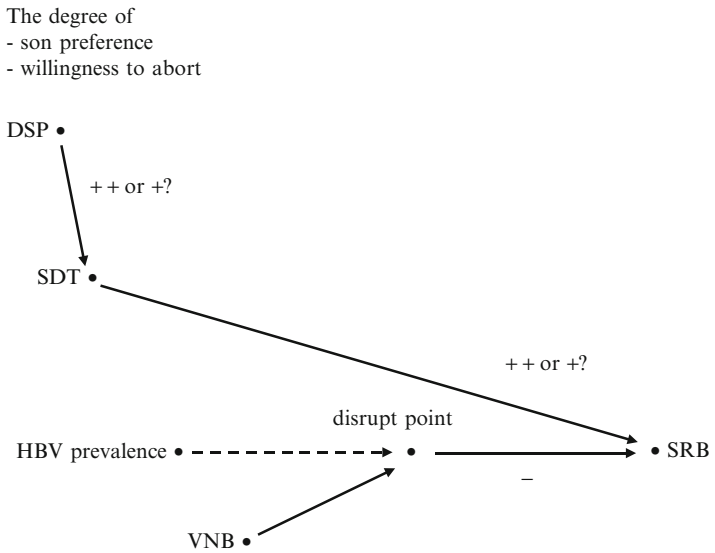

Fig. 12.4 The relatively most complete causal structure with the cultural and biological causal paths

depicted in Fig. 12.3 is revised into the new structure represented in Fig. 12.4. Depending on whether the population has a high or a low degree of son preference, SDT will have very strong positive (++) or mild positive (+) effect on increasing SRB. In other words, if a high percentage of the population prefers having sons, the VNB's effect of decreasing SRB would be much lower than it would otherwise be. In contrast, if most people in the population are indifferent to their offspring's gender, then the indicators estimated from Taiwan's vaccination campaign representing the correlation between HBV prevalence and SRB likely would more reliably reflect the VNB's undisturbed magnitude of the effect on decreasing SRB.

Note that the upper part of Fig. 12.4 represents the cultural and social causal paths that are formed by the connections of the cultural causes and would have a certain degree of influence on SRB, and the lower part of the figure consists of the biological causal paths that are shaped by the combinations of the biological causes and would also have a certain degree of effect on SRB. Also note that, in the process of building the relatively most complicated causal structure represented in Fig. 12.4, at each step an additional causal path is appended to the original relatively simple causal structure to form a relatively more complex figure; one important characteristic of the theory-building methodology is that, in the end, both the cultural and the biological groups of causal paths seem to be accommodated by the relatively most complicated causal structure to form the relatively most complete causal story. It is obvious that, in our description of the methodology, no win-lose strategy is applied in choosing between two competing causal stories. What it shows is that these two competing causal stories complement each other to form a more complete causal story.

This complementary methodology can also be illustrated by the debate between Das Gupta and Oster. According to Das Gupta, the change of sex ratio at birth is so closely correlated with the sex composition of the existing children in the family that it is very unlikely that biological factors could play any significant role in determining that ratio; she therefore concluded that the cultural explanation should replace the biological one. In response, Oster provided a miniature formal model to show that, regardless of the naturally occurring average, resource-constrained utility-maximizing parents would still behave in a way that has the marginal effect of changing the sex ratios (Oster 2006, pp. 326–327). In addition to the formal presentation of the difference between the average and marginal effects, Oster gave an example to illustrate her main point. Consider that there are two countries: country A is in the desert, and country B is in the Arctic. On average, due to its location, country A is hotter than country B. Imagine that we also observe that country A is cooler when the weather is cloudy, and country B is hotter when the weather is sunny. It is obvious that we won't therefore conclude that the entire difference between the weather of country A and that of country B is cloud cover; instead, we would say that "there is a *naturally occurring difference* in the *average* temperature but on the *margin* the temperature in both places can move" (Oster 2006, p. 325; emphasis added).

Thus, we can interpret Oster's example in terms of Cartwright's notions of causal structure and capacity. HBV can be regarded as a factor possessing the capacity to produce a naturally occurring difference—that is, a change in sex ratio at birth—if unimpeded. In the actual world, economists surely know that no factor can operate in an undisturbed environment. They, however, can *assume* that the various effects of these disturbances can be averaged out so that the phenomenon of interest—normally a relation between two targeted factors—can be observed *as if* the observed phenomenon were undisturbed. By using the ideas of capacity and causal structure, we can thus describe the positive relation between HBV (targeted factor 1) and sex ratio at birth (targeted factor 2) as a net result produced by HBV's capacity under a stable causal structure; the various effects of the relevant factors are all averaged out except the two targeted factors. According to such thinking, we can thus suppose that HBV, on average, can have a positive effect on the sex ratio.

Next, by following the logic illustrated in Oster's weather analogy, let's suppose that there are two countries: country A, which has a high percentage of HBV-infected population, and country B, which has low rate of HBV infection. And let's further suppose that we observe that people in country A have no tendency for son preference, but people in country B, for local reasons (such as the need to have more males to do hard agricultural work), prefer having more male births. We can then expect that when the families in country B already have two girls, they will try their best—for example, they may try fetal sex-determination technology—to have a boy in their third birth. As a result, in country B, we can observe a high correlation between the sex of the previous children in a family and the sex ratio of subsequent births. Therefore, just as we may perceive in the weather example that "there is a naturally occurring difference in the average temperature but on the margin the temperature in both places can move," we can also observe in the HBV case that

there is a naturally occurring difference in the average sex ratio (country A, due to the effect of HBV, on average has a higher sex ratio than country B) but on the margin the sex ratio in both places can move (country B, due to its own local concern, may have a higher sex ratio than it would normally have). In the case of country B, we observe that there is a negative relation between HBV and sex ratio, a result that is contradictory to what is described in the capacity claim of HBV (HBV is a factor possessing the capacity to produce a positive change in sex ratio). However, just as we have noted in the discussion of causal structure and capacity, this paradoxical conclusion can be reconciled by resorting to a change in the original structure. Our original simple causal structure contains only one causal path: the HBV infection rate of country B leads directly to the sex ratio at birth of country B. To accommodate the new fact that country B is a son-preference country, we need to add a new causal path leading from country B's degree of son preference to its sex ratio at birth. These two causal paths together constitute a more complicated new causal model from which a new net result—a negative association between HBV and the sex ratio—is generated.

7 The Causal Images of Mechanisms

We have identified two methodological approaches in the missing-women debate: substitutive and complementary. We have also argued that the complementary approach can be understood as an attempt to identify the causal structure. Studies that seem to significantly conflict (such as Blumberg and Oster 2007) with the test that is regarded as decisive (i.e., Lin and Luoh 2008) may be interpreted as attempts to find the strengths of causal paths. Because it is the net result of the causal structure that the empirical test tests against, the data cannot reject the existence of the causal structure. All in all, there is an image of a causal structure in scientists' minds.

Because of the influence of the received image of science, we often find that empirical economists refer to correlation and regularity but seldom discuss mechanism. In the sense of Machamer et al. (2000), we can say that the genuine underlying structure that produces the phenomenon of the correlation between HBV and sex ratio at birth—be it a positive or a negative relation—is the mechanism that makes the relation what it is. When the manifest regularity between HBV and sex ratio at birth is a positive relation, it is the mechanism that makes it so; when the regularity is a negative one, it is still the mechanism that makes it so, but, this time, the mechanism operates under a different structure that makes the originally positive relation become negative. By ignoring the underlying mechanism, the biological explanation is ruled out simply because a robust relation between HBV and sex ratio at birth can no longer be found. However, a faint image of causal structure—like Machamer, Darden, and Craver's mechanism schemata and sketches of the underlying mechanisms—is still possessed by anyone who is interested in the missing-women phenomenon. We can infer a great many possible

situations that may correspond to the causal structure of the sea of disturbances; then, based on this partial causal image, we thus append a complementary causal story to our original biological explanation, as in our case of the missing women, to make the explanation more complete and plausible.[6]

This patch-up methodology is not conducted for the purpose of preserving a falsified hypothesis; instead, the methodology is supplemented with the process of theory-building in an attempt to obtain—as illustrated in our case—a more complete understanding of the targeted phenomenon, be it a normal or an anomalous one.

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[6] For the study of causal images, see Chen (2011).

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