Equity and Distributional Impact on Stunting of a Nutritional Package Targeting Children Aged 6–36 Months in China: Findings from a Modeling Study

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Abstract: Background: Despite rapid economic development, child stunting remains a persistent problem in China. Stunting prevalence varies greatly across geographical regions and wealth groups. To address child undernutrition, the Ying Yang Bao (YYB) nutritional package has been piloted in China since 2001. Objective: We aimed to evaluate the distributional impact of a hypothetical rollout of the YYB nutritional package on child stunting across provinces and wealth groups in China, with a specific focus on equity. Methods: We used data from China Family Panel Studies and built on extended cost-effectiveness analysis methods. We estimated the distributional impact of a 12-month YYB program targeting children aged 6–36 months across 25 provinces and two wealth groups along three dimensions: the cost of the YYB program; the number of child stunting cases averted by YYB; and the cost per stunting case averted. Children in each province were divided into poverty and non-poverty groups based on the international poverty line of $5.50 per day. We also conducted a range of sensitivity analyses. Results: We showed that 75% coverage of YYB could avert 1.9 million stunting cases among children aged 6–36 months, including 1.3 million stunting cases among children living under the poverty line, at a total cost of ¥5.4–6.2 billion ($1.5–1.8 billion) depending on the type of YYB delivery. The cost per stunting case averted would greatly vary across Chinese provinces and wealth groups, ranging from ¥800 (around $220, Chongqing province) to ¥23,300 (around $6600, Jilin province). In most provinces, the cost per stunting case averted would be lower for children living under the poverty line. Conclusions: YYB could be a pro-poor nutritional intervention package that brings substantial health benefits to poor and marginalized Chinese children, but with large variations in value for money across provinces and wealth groups. This analysis points to the need for prioritization across provinces and a targeted approach for YYB rollout in China.

Keywords: nutritional package; Ying Yang Bao; child stunting; equity; distributional impact; extended cost-effectiveness analysis

1. Introduction

As of 2015, China was home to 86 million children under 5 years of age, accounting for 13% of the world’s under-five population [1]. Despite rapid economic growth, China still has large numbers of stunted children (height-for-age Z score less than minus 2 standard deviations (SD)); it is estimated that 10% of Chinese children under five years old were stunted in 2016, equal to about 9 million children [2]. There are large disparities in child stunting rates within China, with a prevalence ranging from 4% in urban areas to 16% in rural areas, and from being almost absent in rich provinces and cities such as Beijing, Tianjin and Shanghai to being as prevalent as 29% in poor provinces and cities such as Guizhou and Sichuan.
as Sichuan and Gansu [2]. Previous evidence shows that stunting in children under age five could lead to impaired cognitive development, affecting educational performance and long-term economic productivity [3–5]. Often, children living in poor families and regions of China are more likely to be stuck in a cycle of poverty as stunting can be both a cause and a consequence of poverty [6].

To improve children’s nutritional status in China, the Ying Yang Bao (YYB) nutritional package was introduced to the country’s poor rural areas in 2001 [7]. YYB is a nutrient-dense food supplement targeting infants and young children, usually aged 6–36 months. The base of YYB is constituted of full fat soybean powder and multiple micronutrient powders, including calcium, iron, zinc and vitamins; folic acid, omega 3, omega 6, thiamin and riboflavin are also sometimes added [7–9]. The exact composition of YYB varies slightly, depending on the manufacturing companies. Compared to other complementary feeding supplements (e.g., sprinkles and crushable tablets) that only provide micronutrients, YYB contains soybean powder that provides both calories (usually ~50 Kcal per pack) and protein (3 g per pack) in addition to various micronutrients [7–9]. YYB can be directly added to children’s meals (e.g., mushy foods, soups and noodles) or reconstituted with water [10].

The YYB program was first piloted and launched in 2001 in five counties of Gansu province and targeted 4–12-month-olds [11]. Since then, it gradually expanded to other poor rural areas of China and regions affected by natural disasters. In 2011, the Chinese government invested ¥100 million ($28 million, 2011 Purchasing Power Parity (PPP)) for the YYB program covering 300,000 children in 100 counties across 10 provinces [12]. In 2017, the Chinese government issued a national nutrition strategy (for the years 2017–2030) that clearly prioritized the promotion of nutritional status of children in their first 1000 days [13]; and YYB was considered as one key intervention for rural and poor populations [13]. In 2019, the Chinese government launched the “Upgrade of YYB Plan” and has started to expand YYB coverage to all 823 counties living in poverty in the country [14].

Previous studies consistently demonstrated the effectiveness of YYB on improving children’s anthropometric status, including children’s height, in a variety of settings [15–20]. A meta-analysis summarizing publications on the effects of YYB over the time period January 2001 to March 2019 showed that YYB was associated with an average 2.46-cm (95% confidence interval (CI): 0.96–3.97) increase in children’s height and with a 40% decrease in stunting prevalence [21]. This meta-analysis covered studies from a great variety of provinces, including provinces with gross domestic product (GDP) per capita higher than $20,000 (e.g., Zhejiang and Jiangsu), provinces with moderate GDP per capita, of $10,000–20,000 (e.g., Hubei and Liaoning) and provinces with GDP per capita lower than $10,000 (e.g., Yunnan and Gansu) [21,22]. This points to the comprehensiveness of the meta-analysis and to the representativeness of the identified effect size in China. However, little work has assessed the cost-effectiveness of YYB delivery and its equity impact on child stunting across China’s provinces and wealth groups. In this study, we built on extended cost-effectiveness analysis (ECEA) methods [23,24] to study the distributional consequences of YYB rollout in China.

2. Methods

We developed an epidemiological model to estimate the cost, health benefits and cost-effectiveness of a hypothetical YYB program rolled out across 25 provinces and two wealth groups in China.

2.1. Setting

To be consistent with the previous studies evaluating the effects of YYB interventions [21], we focused on children from rural areas and aged 6–36 months, assuming that all Chinese children who satisfied the inclusion criteria would be covered by the hypothetical YYB program. The YYB intervention was assumed to be rolled out over 12 months based on current YYB practices, and the children targeted by the intervention would receive one YYB pack per day [10,25]. We examined the distributional consequences of YYB on child stunting across 25 Chinese provinces and two wealth groups. The two wealth groups were defined according to the World Bank’s international poverty line: those living under the international poverty line ($5.5 (2011 PPP) or ¥19.4 (2011 RMB) per day) [26,27]...
and those living above this poverty line. We simulated two coverage scenarios: a low coverage (25%) and a high coverage (75%) scenario.

2.2. Data Sources

We used data on stunting prevalence and household poverty status from the China Family Panel Studies (CFPS) [2]. CFPS is a nationally representative, longitudinal survey launched in 2010 and further conducted in 2012, 2014 and 2016. It covers about 16,000 households across 25 provinces, municipalities, and autonomous regions of China, representing up to 95% of 6–36 month-old Chinese. To calculate stunting prevalence, we standardized height by age and gender using the Z-score method: following the World Health Organization guidelines, we defined stunting as height-for-age Z score (HAZ) below minus 2SD [28]. CFPS also presents self-reported data on household income per capita, which we compared with the poverty line of ¥19.4 RMB per day [29]. We could then identify whether a child in a household lived in poverty or not. CFPS did not collect information on whether the children were already receiving YYB or not. However, only around 1% of children were covered by the program in 2015 [30], indicating very minimal impact of the existing program. Therefore, we assumed that the children included in the CFPS were not covered by the YYB program.

2.3. Estimation of Health Benefits

The health gains were defined as the number of child stunting cases that would be averted by YYB per province and wealth group: First, we estimated the population aged 6–36 months in province \( p \) and with poverty status \( k \), denoted \( \text{POP}_{p,k} \). Second, for each child (denoted “i”) in the dataset, we checked his/her original height (Height\(_{pre,p,k,i}\)) and standardized it with child age and sex to obtain HAZ. We determined whether the child was stunted by examining whether his/her HAZ (HAZ\(_{pre,p,k,i}\)) was below minus 2SD. The stunting prevalence without hypothetical rollout of YYB in province \( p \) for poverty status \( k \), denoted \( S_{pre,p,k} \), was the probability for a child in that subgroup to be stunted. Third, we used an estimate of YYB effectiveness [21] (denoted \( \text{Eff} \)) to estimate the impact of YYB on child height. We assumed \( \text{Eff} \) to be the same for all children. The likelihood for a child to be covered by YYB is denoted as \( \text{Cov}_p \) (for province \( p \)). The expected post-intervention height of child \( i \) (Height\(_{post,p,k,i}\)) could be expressed using the following static model:

\[
\text{Height}_{post,p,k,i} = \text{Height}_{pre,p,k,i} + \text{Eff} \times \text{Cov}_p
\]

We checked the post-intervention stunting status of each child (HAZ\(_{post,p,k,i}\)) by examining whether Height\(_{post,p,k,i}\) was below minus 2SD. We then estimated post-intervention stunting prevalence in province \( p \) and for poverty status \( k \) (S\(_{post,p,k}\)) by counting how many children had HAZ\(_{post,p,k,i}\) below minus 2SD. Hence, the number of stunting cases averted (AVERT\(_{p,k}\)) is calculated as:

\[
\text{AVERT}_{p,k} = \text{POP}_{p,k} \times (S_{pre,p,k} - S_{post,p,k})
\]

2.4. Estimation of Costs

According to previous reports and studies [31–33], the YYB intervention would include four cost components: procurement and manufacturing costs; implementation costs; advertisement costs; and transportation costs (see Table S1 for further detail). The first three cost components were largely fixed, while transportation costs were assumed to vary based on transportation availability and accessibility across provinces and the type of YYB delivery to children and their households.

Procurement and manufacturing costs (M) were estimated at 35.0 cents (RMB; 9.9 cents ($)) per YYB pack, including manufacturing, printing for educational materials, personnel training for distribution and storage [31–33]. Implementation costs (F) included the costs imposed on township hospitals, village health posts and other organizations required to coordinate the delivery of YYB: F was estimated at 17.9 cents (RMB; 5.1 cents ($)) per pack [31]. Advertisement costs (A) were estimated
at 16.7 cents (RMB; 4.7 cents ($)) per pack and covered raising public awareness and training of staff for implementation [31].

The transportation costs in province p and for poverty status k were denoted $T_{p,k}$, which included the delivery costs from manufacturing companies to eligible households. $T_{p,k}$ was composed of two parts (Figure 1). The first is the transportation costs from manufacturing companies to township hospitals ($TM_p$), and these costs were borne by manufacturing companies. According to published studies [31–33], $TM_p$ would vary greatly depending on accessibility and distance to township hospitals, from about 0.9 to 13.5 cents (RMB; 0.3 to 3.8 cents ($)) per YYB pack. Second, the costs from township hospitals to households, which could be materialized in two ways depending on the delivery type. There were two main ways to deliver YYB, denoted “Delivery Type 1” and “Delivery Type 2” [31]. Delivery Type 1 corresponds to the situation where village doctors come to the hospitals every month to collect YYB, and village health posts serve as the distribution location for caregivers to obtain YYB for their children. The costs borne by the village doctors ($TV_p$ in province p) would be subsidized by the government [31]. We accounted for the time losses borne by the caregivers ($TH_{p,k}$, for households of wealth status k in province p). Delivery Type 2 corresponds to the situation where caregivers come to township hospitals monthly to get YYB at their own expenses ($TO_{p,k}$).

Figure 1. The types of delivery and associated costs for YYB, from manufacturing companies to eligible children.

Transportation costs ($T_p$) were expected to vary with two major factors: accessibility and distance from manufacturing companies to township hospitals and delivery type. For the first factor, road density was a critical determinant [31,34]. A number of studies on forest management used road density to estimate transportation costs [34–38]. We followed these studies [37,39] and modeled transportation costs from manufacturing companies to township hospitals in province p ($TM_p$) based on the local road network density (denoted $R_p$) (Figure S1). We assumed transportation costs would increase linearly with lower road density: the province with the largest $R_p$ (Shanghai, 208 km per 100 km$^2$ of land area) would face the lower transportation costs (0.9 cents (RMB; 0.3 cents ($)) per pack), while the province with the lowest $R_p$ (Gansu, 31 km per 100 km$^2$) would face the higher transportation costs (13.5 cents (RMB; 3.8 cents ($)) per pack). Subsequently, we could express the transportation costs from manufacturing companies to township hospitals (in cents, RMB) per pack in province p as: $TM_p = 13.5 - (13.5 - 0.9)/(208 - 31)*(R_p - 31)$. For the second component, we modeled two delivery types. Delivery Type 1 is where village doctors would come to township hospitals every month to collect YYB at 0.9 cents per pack (RMB; 0.3 cents ($)) [31]. Caregivers would come to village health posts monthly to obtain YYB for their children. Following previous practices [2,40–43], we calculated caregivers’ time costs ($TH_{p,k}$) in the following way: we multiplied caregivers’ travel time to health posts with provincial-level GDP per capita. Caregivers’ travel time was sourced from CFPS data and provincial-level GDP per capita data from the China Statistical Yearbook. Delivery Type 2 is where caregivers would come to township hospitals monthly to obtain YYB. The time costs to township hospitals ($TO_{p,k}$) were borne by caregivers: CFPS did not collect information on travel
time to township hospitals, so we imputed the travel time to the nearest town. We multiplied travel time by province-level GDP per capita to estimate the time costs for caregiver travel to township hospitals (TO<sub>p,k</sub>).

The estimated total transportation costs could then be expressed as: T<sub>p,k</sub> = TM<sub>p</sub> + TV<sub>p</sub> + TH<sub>p,k</sub> for Delivery Type 1 and T<sub>p,k</sub> = TM<sub>p</sub> + TO<sub>p,k</sub> for Delivery Type 2. Subsequently, the total costs per pack could be calculated as: PP<sub>p,k</sub> = M + F + A + T<sub>p,k</sub>. Lastly, the total costs per province p and wealth status k, for 12 months (365 days), could be estimated as PP<sub>p,k</sub>, multiplied by POP<sub>p,k</sub>, Cov<sub>p,k</sub>, 365 and the number of YYB packs needed for a 12-month intervention.

All types of costs were expressed both in 2011 RMB and international dollars. An incremental cost-effectiveness ratio was computed in terms of cost per stunting case averted.

2.5. Sensitivity Analyses

To test the robustness of our findings, we conducted two sets of sensitivity analyses. First, we examined the impact of YYB effectiveness by halving the original effectiveness Eff. This sensitivity analysis could capture variations in Eff potentially caused by household adherence and acceptability: previous studies showed that adherence of YYB program was around 80% and acceptability around 70% [8,9]. Likewise, we further tested a YYB effectiveness set to the lower bound of the 95% confidence interval of the estimated effect size from the meta-analysis (i.e., 0.96 cm) [21]. Second, we studied the impact of transportation costs by either halving or doubling transportation costs for Delivery Types 1 and 2, respectively. This sensitivity analysis could materialize economies of scale: transportation costs per capita may decrease with increasing coverage (e.g., from 25% to 75%); in addition, if many households lived in remote or mountainous areas, transportation costs per capita might increase with higher YYB coverage. In other words, this sensitivity analysis could test the variability in transportation costs across settings. For each sensitivity analysis, we reported on the resulting variations in costs, health benefits and cost-effectiveness in province p and for wealth group k.

3. Results

We first report on the different components of transportation costs (Tables S2 and S3). The average transportation costs from manufacturing companies to township hospitals were estimated to be 8.1 cents (RMB; 2.3 cents ($)) per pack. On average, caregivers’ transportation costs to health posts were 0.9 cents (RMB; 0.3 cents ($)) per pack, while caregivers’ transportation costs to township hospitals were estimated at 8.3 cents (RMB; 2.4 cents ($)) per pack. Tables S4 and S5 present the estimated transportation costs by YYB delivery type (Type 1 vs. Type 2). In all provinces, the transportation costs were lower with Delivery Type 1 (9.9–10.2 cents (RMB; 2.8–2.9 cents ($)) on average) compared to Delivery Type 2 (16.8–25.2 cents (RMB; 4.8–7.2 cents ($)) on average). We estimated the costs per pack for each province and wealth group (Tables S6 and S7), as well as the total estimated costs at 25% and 75% coverage levels (Tables S8 and S9). At 25% coverage, the total costs would be estimated at ¥0.8–1.0 billion ($0.23–0.28 billion) for Delivery Type 1, compared with ¥0.9–1.2 billion ($0.26–0.34 billion) for Delivery Type 2.

Second, we estimated the health gains conferred by YYB. Before YYB intervention, stunting prevalence would vary substantially by province and poverty status (Table S10): Yunnan had the highest stunting prevalence at 27% (poverty group), while Beijing, Tianjin and Shanghai had the lowest stunting prevalence (about null). With 25% coverage of YYB, the estimated stunting prevalence in Yunnan would go down to 24% (poverty group); with 75% coverage, it would further decrease to 16% (Table S10).

Overall, there was about 4.0 million stunted children before YYB intervention, including 2.7 million among the poverty group. Henan had the largest number of stunted children (about 0.4 million), while Beijing, Tianjin, Shanghai and Zhejiang had the lowest numbers (cumulatively less than 10,000) (Table S11). The estimated impact of YYB would then vary greatly by province and wealth status. Nationally, with 25% coverage, around 0.6 million stunting cases could be averted, including 0.4 million...
cases for the poverty group; with 75% YYB coverage, a total of 1.9 million stunting cases could be averted, including 1.3 million cases for the poverty group. Jiangxi would rank first in terms of stunting cases averted (about 80,000), while Beijing, Tianjin, Shanghai and Zhejiang would rank last (cumulatively less than 3000) (see Table 1).

**Table 1.** Number of stunting cases averted by YYB program, by province and poverty status (25% and 75% coverage).

| Province     | 25% Coverage Below Poverty Line | 25% Coverage Above Poverty Line | 75% Coverage Below Poverty Line | 75% Coverage Above Poverty Line |
|--------------|--------------------------------|---------------------------------|--------------------------------|---------------------------------|
| Anhui        | 4074                           | 5431                            | 25,799                         | 9310                            |
| Beijing      | 0                              | 0                               | 0                              | 0                               |
| Chongqing    | 24,076                         | 0                               | 29,694                         | 0                               |
| Fujian       | 4982                           | 4095                            | 18,286                         | 25,516                          |
| Gansu        | 9424                           | 1261                            | 29,779                         | 5374                            |
| Guangdong    | 32,623                         | 20,678                          | 76,022                         | 57,978                          |
| Guangxi      | 33,337                         | 5598                            | 68,566                         | 43,095                          |
| Guizhou      | 14,453                         | 6509                            | 54,751                         | 22,093                          |
| Hebei        | 48,005                         | 6549                            | 121,902                        | 20,565                          |
| Heilongjiang | 8310                           | 0                               | 34,462                         | 0                               |
| Henan        | 11,561                         | 24,716                          | 117,388                        | 91,953                          |
| Hubei        | 5958                           | 5240                            | 30,902                         | 37,334                          |
| Hunan        | 7273                           | 16,428                          | 71,374                         | 55,224                          |
| Jiangsu      | 33,834                         | 45,338                          | 100,104                        | 76,668                          |
| Jilin        | 3392                           | 746                             | 14,379                         | 13,234                          |
| Liaoning     | 4588                           | 1224                            | 14,681                         | 4468                            |
| Shaanxi      | 11,207                         | 2074                            | 43,072                         | 13,958                          |
| Shandong     | 33,804                         | 4243                            | 109,862                        | 27,094                          |
| Shanghai     | 0                              | 0                               | 0                              | 0                               |
| Shandong     | 8710                           | 4296                            | 31,960                         | 23,949                          |
| Sichuan      | 48,825                         | 18,957                          | 146,474                        | 28,088                          |
| Tianjin      | 0                              | 0                               | 0                              | 0                               |
| Yunnan       | 30,226                         | 3318                            | 106,351                        | 33,686                          |
| Zhejiang     | 2955                           | 0                               | 6456                           | 0                               |
| Total        | 387,538                        | 183,284                         | 1,275,515                      | 621,907                         |

We present the cost per stunting case averted per province and poverty group in Table 2 (and Table S12). The cost per stunting case averted was generally lower with YYB Delivery Type 1. Among all provinces, targeting children in poverty in Chongqing (25% coverage, Type 1) would yield the lowest cost per stunting case averted (about ¥800 or $220 per stunted case). Conversely, targeting children not in poverty in Jilin province with Delivery Type 2 would yield the highest cost per stunting case averted (about ¥23,300 or $6600).

**Sensitivity Analyses**

First, when halving the effect size of YYB, as expected, the cost per stunting case averted increased. The cost per stunting case averted was maintained lower with Delivery Type 1 (than with Delivery Type 2). The cost per stunting case averted remained lowest in Chongqing (about ¥1600 or $450 with Delivery Type 1 targeting children in poverty), while it would remain highest in Anhui (about ¥51,200 ($14,500) with Delivery Type 2 targeting children not in poverty) (Table 3 and Table S13). Likewise, when we reduced the effect size of YYB to 0.96 cm (the lower bound of the estimated effect size from the meta-analysis [21]), the cost per stunting case averted increased, but with Chongqing and Anhui remaining the lowest and highest, respectively (Table 4 and Table S14). Third, when the cost of YYB was halved, our key distributional findings would remain the same (Table 5 and Table S15). Notably, targeting children in poverty in Chongqing with Delivery Type 1 would still yield the lowest cost per stunting case averted (about ¥750 ($210)). When the cost of YYB was doubled, our distributional findings would hold as well (Table 5 and Table S15).
Table 2. Cost-effectiveness of YYB program, by province and poverty status (Cost (¥) per stunting case averted).

| Province  | 25% Coverage Below Poverty Line | 25% Coverage Above Poverty Line | 75% Coverage Below Poverty Line | 75% Coverage Above Poverty Line |
|-----------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|           | Delivery Type 1                  | Delivery Type 2                  | Delivery Type 1                  | Delivery Type 2                  |
| Anhui     | 11,684                          | 18,385                          | 5531                            | 8710                            |
| Beijing   | NA                              | NA                              | NA                              | NA                              |
| Chongqing | 785                             | 1213                            | 1906                            | 2953                            |
| Fujian    | 4175                            | 4476                            | 3418                            | 2877                            |
| Gansu     | 3417                            | 3661                            | 3244                            | 7741                            |
| Guangdong | 1858                            | 2474                            | 2393                            | 2494                            |
| Guangxi   | 2013                            | 2362                            | 2955                            | 2945                            |
| Guizhou   | 3660                            | 4248                            | 2900                            | 3177                            |
| Hebei     | 1733                            | 2075                            | 2048                            | 2450                            |
| Heilongjiang | 2756                        | 2888                            | 1991                            | 2086                            |
| Henan     | 9558                            | 10,077                          | 2823                            | 2976                            |
| Hubei     | 4851                            | 5421                            | 2809                            | 3136                            |
| Hunan     | 7851                            | 966                             | 2401                            | 2983                            |
| Jiangsu   | 2936                            | 3093                            | 2168                            | 2284                            |
| Jiangxi   | 1578                            | 1699                            | 1599                            | 1724                            |
| Jilin     | 4186                            | 4511                            | 2963                            | 3199                            |
| Liaoning  | 3684                            | 5536                            | 3447                            | 5184                            |
| Shaanxi   | 2954                            | 3650                            | 2305                            | 2851                            |
| Shandong  | 2000                            | 2151                            | 1846                            | 1985                            |
| Shanghai  | NA                              | NA                              | NA                              | NA                              |
| Shanxi    | 2859                            | 3042                            | 2340                            | 2491                            |
| Sichuan   | 2153                            | 2245                            | 2153                            | 2245                            |
| Tianjin   | NA                              | NA                              | NA                              | NA                              |
| Yunnan    | 2309                            | 3487                            | 1969                            | 2973                            |
| Zhejiang  | 2707                            | 2707                            | 3702                            | 3717                            |

Notes: Delivery Type 1: Manufacturing companies deliver YYB to township hospitals; then, village doctors come to township hospitals to collect YYB monthly and caregivers get YYB from village health posts. Delivery Type 2: Manufacturing companies deliver YYBs to township hospitals; then, caregivers come to township hospitals monthly to obtain YYB. NA means the values are not available.
Table 3. Cost-effectiveness of YYB program, by province and poverty status, when the effect size of YYB is halved (Cost (¥) per stunting case averted).

| Province  | 25% Coverage | 75% Coverage |
|-----------|--------------|--------------|
|           | Delivery Type 1 | Delivery Type 2 | Delivery Type 1 | Delivery Type 2 |
|           | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line |
| Anhui     | 18,421        | 38,571        | 28,997        | 51,179        | 11,052        | 24,302        | 17,397        | 32,233        |
| Beijing   | NA            | NA            | NA            | NA            | NA            | NA            | NA            | NA            |
| Chongqing | 1593          | 2468          | NA            | NA            | 3987          | NA            | 6179          | NA            |
| Fujian    | 6662          | 16,118        | 7127          | 17,107        | 6334          | 6059          | 6774          | 6428          |
| Gansu     | 5823          | 44,268        | 6231          | 43,910        | 6907          | 15,083        | 7392          | 14,924        |
| Guangdong | 4371          | 5087          | 5815          | 5419          | 4538          | 4784          | 6038          | 5096          |
| Guangxi   | 3788          | 11,137        | 4442          | 11,703        | 6181          | 6093          | 7249          | 6402          |
| Guizhou   | 5851          | 9590          | 6786          | 9520          | 5662          | 6959          | 6567          | 6906          |
| Hebei     | 4043          | 11,384        | 4838          | 12,110        | 4110          | 12,053        | 4918          | 12,823        |
| Heilongjiang | 5158        | NA            | 5409          | NA            | 3961          | NA            | 4154          | NA            |
| Henan     | 19,423        | 9672          | 20,478        | 10,157        | 5407          | 6102          | 5701          | 6408          |
| Hubei     | 11,120        | 15,866        | 12,414        | 18,597        | 5638          | 7405          | 6295          | 8678          |
| Hunan     | 12,386        | 8699          | 15,391        | 10,190        | 5031          | 6353          | 6250          | 7442          |
| Jiangsu   | 4777          | 10,067        | 5028          | 10,610        | 4607          | 10,145        | 4849          | 10,693        |
| Jiangxi   | 2878          | 1995          | 3104          | 2181          | 3204          | 3447          | 3455          | 3769          |
| Jilin     | 9073          | 37,802        | 9789          | 46,774        | 6100          | 5918          | 6582          | 7333          |
| Liaoning  | 14,457        | 27,002        | 21,728        | 27,002        | 8501          | 18,796        | 12,779        | 18,796        |
| Shaanxi   | 6167          | 14,314        | 7632          | 16,284        | 4468          | 6256          | 5529          | 7117          |
| Shandong  | 3947          | 33,333        | 4246          | 33,194        | 3712          | 14,167        | 3992          | 14,113        |
| Shanghai  | NA            | NA            | NA            | NA            | NA            | NA            | NA            | NA            |
| Shanxi    | 5164          | 12,918        | 5498          | 12,977        | 4609          | 4699          | 4906          | 4722          |
| Sichuan   | 4469          | 3074          | 4658          | 3632          | 4545          | 6024          | 4737          | 7117          |
| Tianjin   | NA            | NA            | NA            | NA            | NA            | NA            | NA            | NA            |
| Yunnan    | 4221          | 9083          | 6373          | 9926          | 3844          | 4140          | 5803          | 4524          |
| Zhejiang  | 5559          | NA            | 5587          | NA            | 8093          | NA            | 8133          | NA            |

Notes: Delivery Type 1: Manufacturing companies deliver YYB to township hospitals; then, village doctors come to township hospitals to collect YYB monthly and caregivers get YYB from village health posts. Delivery Type 2: Manufacturing companies deliver YYB to township hospitals; then, caregivers come to township hospitals monthly to obtain YYB.
Table 4. Cost-effectiveness of YYB program, by province and poverty status, when the effect size of YYB is reduced to 0.96 cm (Cost (¥) per stunting case averted).

| Province   | Province | 25% Coverage | 75% Coverage |
|------------|----------|--------------|--------------|
|             | Delivery Type 1 | Delivery Type 2 | Delivery Type 1 | Delivery Type 2 |
|             | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line |
| Anhui      | 20,877 | 55,670 | 33,907 | 61,092 | 12,122 | 28,551 | 21,457 | 35,357 |
| Beijing    | NA     | NA     | NA     | NA     | NA     | NA     | NA     | NA     |
| Chongqing  | 1934   | NA     | 2605   | NA     | 4800   | NA     | 6625   | NA     |
| Fujian     | 8251   | 19,679 | 8001   | 17,899 | 7141   | 6816   | 7041   | 7759   |
| Gansu      | 6189   | 46,179 | 7453   | 56,612 | 9198   | 17,620 | 9356   | 19,590 |
| Guangdong  | 5391   | 5402   | 8015   | 5923   | 5255   | 5632   | 6926   | 5614   |
| Guangxi    | 4328   | 12,646 | 5415   | 12,444 | 6584   | 6984   | 8542   | 7652   |
| Guizhou    | 6921   | 10,919 | 7675   | 11,588 | 6763   | 7799   | 8439   | 8393   |
| Hebei      | 4890   | 13,634 | 5408   | 13,478 | 5459   | 13,784 | 5565   | 14,377 |
| Heilongjiang| 6639  | NA     | 6879   | NA     | 4156   | NA     | 4569   | NA     |
| Henan      | 24,539 | 12,313 | 27,239 | 10,666 | 5687   | 7362   | 6532   | 6844   |
| Hubei      | 11,446 | 16,776 | 13,168 | 18,805 | 6759   | 8017   | 8210   | 10,621 |
| Hunan      | 12,913 | 9917   | 17,688 | 12,988 | 6809   | 8060   | 7738   | 8749   |
| Jiangsu    | 5411   | 10,600 | 5607   | 11,223 | 5882   | 10,400 | 5976   | 13,235 |
| Jiangxi    | 3099   | 2438   | 3587   | 2606   | 3947   | 3635   | 4428   | 4323   |
| Jilin      | 10,931 | 46,689 | 10,275 | 60,000 | 6804   | 7082   | 6745   | 8341   |
| Liaoning   | 21,338 | 29,234 | 26,625 | 34,198 | 10,775 | 23,012 | 14,468 | 24,178 |
| Shaanxi    | 8187   | 18,263 | 7792   | 17,698 | 5260   | 7416   | 6918   | 9204   |
| Shandong   | 4603   | 41,443 | 5430   | 42,857 | 4682   | 19,065 | 5245   | 19,242 |
| Shanghai   | NA     | NA     | NA     | NA     | NA     | NA     | NA     | NA     |
| Shanxi     | 5950   | 18,363 | 6996   | 15,109 | 5688   | 5533   | 5841   | 5661   |
| Sichuan    | 5798   | 3575   | 5784   | 3960   | 5123   | 6915   | 5921   | 8785   |
| Tianjin    | NA     | NA     | NA     | NA     | NA     | NA     | NA     | NA     |
| Yunnan     | 5455   | 10,302 | 7399   | 10,867 | 4113   | 5167   | 6899   | 5454   |
| Zhejiang   | 7435   | 6375   | NA     | 8958   | NA     | 9566   | NA     | --     |

Notes: Delivery Type 1: Manufacturing companies deliver YYB to township hospitals; then, village doctors come to township hospitals to collect YYB monthly and caregivers get YYB from village health posts. Delivery Type 2: Manufacturing companies deliver YYB to township hospitals; then, caregivers come to township hospitals monthly to obtain YYB.
| Province       | Delivery Type 1 | Delivery Type 2 | Delivery Type 1 | Delivery Type 2 |
|---------------|----------------|----------------|----------------|----------------|
|               | 25% Coverage    | 75% Coverage    | 25% Coverage    | 75% Coverage    |
|               | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line |
| Anhui         | 11,133         | 9510           | 14,486         | 11,133         |
| Beijing       | NA             | NA             | NA             | NA             |
| Chongqing     | 745            | NA             | 960            | NA             |
| Fujian        | 3894           | 5568           | 4039           | 5749           |
| Gansu         | 3120           | 9967           | 3240           | 9909           |
| Guangdong     | 1754           | 2205           | 2061           | 2281           |
| Guangxi       | 1830           | 6875           | 2004           | 7067           |
| Guizhou       | 3422           | 3384           | 3715           | 3371           |
| Hebei         | 1622           | 6821           | 1792           | 7054           |
| Heilongjiang  | 2513           | NA             | 2581           | NA             |
| Henan         | 9177           | 3646           | 9436           | 3741           |
| Hubei         | 4544           | 8349           | 4827           | 9102           |
| Hunan         | 7379           | 3389           | 8332           | 3702           |
| Jiangsu       | 2815           | 8403           | 2892           | 8640           |
| Jiangxi       | 1471           | 903            | 1533           | 948            |
| Jilin         | 3838           | 17,372         | 4003           | 19,630         |
| Liaoning      | 3417           | 11,005         | 4342           | 11,005         |
| Shandong      | 1907           | 12,464         | 1983           | 12,439         |
| Shanghai      | 2747           | 6413           | 3097           | 6886           |
| Shannxi       | 2668           | 4196           | 2760           | 4207           |
| Sichuan       | 1984           | 1334           | 2030           | 1465           |
| Tianjin       | NA             | NA             | NA             | NA             |
| Yunnan        | 2135           | 6180           | 2722           | 6489           |
| Zhejiang      | 2525           | NA             | 2531           | NA             |

The Cost per Stunting Case Averted Assuming the Transportation Costs of YYB Were Halved (top)/Doubled (bottom)

| Province       | Delivery Type 1 | Delivery Type 2 | Delivery Type 1 | Delivery Type 2 |
|---------------|----------------|----------------|----------------|----------------|
|               | 25% Coverage    | 75% Coverage    | 25% Coverage    | 75% Coverage    |
|               | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line |
| Anhui         | 5273           | 16,642         | 6862           | 19,482         |
| Beijing       | NA             | NA             | NA             | NA             |
| Chongqing     | 1811           | NA             | 2336           | NA             |
| Fujian        | 3182           | 2681           | 3301           | 2768           |
| Gansu         | 2962           | 7014           | 3076           | 6973           |
| Guangdong     | 2258           | 2359           | 2654           | 2440           |
| Guangxi       | 2685           | 2679           | 2940           | 2754           |
| Guizhou       | 2710           | 2991           | 2942           | 2979           |
| Hebei         | 1916           | 6517           | 2117           | 6739           |
| Heilongjiang  | 1818           | NA             | 1867           | NA             |
| Henan         | 2711           | 2940           | 2788           | 3017           |
| Hubei         | 2628           | 3516           | 2792           | 3833           |
| Hunan         | 2256           | 3024           | 2547           | 3303           |
| Jiangsu       | 2078           | 4979           | 2135           | 5119           |
| Jiangxi       | 1492           | 1610           | 1555           | 1690           |
| Jilin         | 2716           | 2936           | 2834           | 3318           |
| Liaoning      | 3203           | 3046           | 9071           | 9046           |
| Shandong      | 2144           | 2859           | 2417           | 3070           |
| Shanghai      | 1760           | 5856           | 1830           | 5844           |
| Shannxi       | 2181           | 2258           | 2257           | 2264           |
| Sichuan       | 1984           | 2700           | 2030           | 2965           |
| Tianjin       | NA             | NA             | NA             | NA             |
| Yunnan        | 1820           | 1826           | 2322           | 1917           |
| Zhejiang      | 3466           | NA             | 3475           | NA             |

The Cost per Stunting Case Averted Assuming the Transportation Costs of YYB Were Halved (top)/Doubled (bottom)

| Province       | Delivery Type 1 | Delivery Type 2 | Delivery Type 1 | Delivery Type 2 |
|---------------|----------------|----------------|----------------|----------------|
|               | 25% Coverage    | 75% Coverage    | 25% Coverage    | 75% Coverage    |
|               | Below Poverty Line | Above Poverty Line | Below Poverty Line | Above Poverty Line |
| Anhui         | 6051           | 18,934         | 12,405         | 30,295         |
| Beijing       | NA             | NA             | NA             | NA             |
| Chongqing     | 2096           | NA             | 4193           | NA             |
| Fujian        | 3882           | 3265           | 4356           | 3615           |
| Gansu         | 3806           | 9171           | 4261           | 9008           |
| Guangdong     | 2661           | 2766           | 4242           | 3092           |
Table 5. Cont.

| Province     | Delivery Type 1 Below Poverty Line | Delivery Type 1 Above Poverty Line | Delivery Type 2 Below Poverty Line | Delivery Type 2 Above Poverty Line | Delivery Type 1 Below Poverty Line The Cost per Stunting Case Averted | Delivery Type 1 Above Poverty Line The Cost per Stunting Case Averted | Delivery Type 2 Below Poverty Line Assuming the Transportation Costs of YYB Were Halved | Delivery Type 2 Above Poverty Line Assuming the Transportation Costs of YYB Were Halved |
|--------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|
| Guangxi      | 2380                              | 8918                              | 3076                              | 9683                              | 3492                                                               | 3475                                                               | 4513                                                           | 3773                                                           |
| Guizhou      | 4143                              | 4014                              | 5313                              | 3959                              | 3281                                                               | 3548                                                               | 4208                                                           | 4208                                                           |
| Hebei        | 1945                              | 8231                              | 2638                              | 9162                              | 2312                                                               | 7864                                                               | 3117                                                           | 8753                                                           |
| Heilongjiang | 3235                              | NA                                | 3493                              | NA                                | 2333                                                               | NA                                                                | 2527                                                           | NA                                                             |
| Henan        | 10,315                            | 4112                              | 11,351                            | 4493                              | 3048                                                               | 3316                                                               | 3354                                                           | 3623                                                           |
| Hubei        | 5475                              | 9581                              | 6606                              | 12,593                            | 3167                                                               | 4034                                                               | 3821                                                           | 5302                                                           |
| Hunan        | 8808                              | 4165                              | 12,616                            | 5415                              | 2692                                                               | 3717                                                               | 3857                                                           | 4833                                                           |
| Jiangsu      | 3186                              | 9495                              | 3495                              | 10,442                            | 2352                                                               | 5626                                                               | 2581                                                           | 6187                                                           |
| Jiangxi      | 1789                              | 1097                              | 2036                              | 1277                              | 1814                                                               | 1954                                                               | 2065                                                           | 2276                                                           |
| Jilin        | 4883                              | 21,854                            | 5545                              | 30,888                            | 3456                                                               | 3694                                                               | 3925                                                           | 5221                                                           |
| Liaoning     | 4199                              | 13,422                            | 7900                              | 13,422                            | 3937                                                               | 11,033                                                             | 7406                                                           | 11,033                                                          |
| Shaanxi      | 3365                              | 7846                              | 4767                              | 9739                              | 2627                                                               | 3498                                                               | 3721                                                           | 4342                                                           |
| Shandong     | 2185                              | 14,472                            | 2487                              | 14,371                            | 2017                                                               | 6799                                                               | 2296                                                           | 6791                                                           |
| Shanghai     | NA                                | NA                                | NA                                | NA                                | NA                                                                  | NA                                                                 | NA                                                             | NA                                                             |
| Shanxi       | 3249                              | 5110                              | 3618                              | 5155                              | 2656                                                               | 2750                                                               | 2658                                                           | 2774                                                           |
| Sichuan      | 2492                              | 1663                              | 2675                              | 2187                              | 2492                                                               | 3368                                                               | 2675                                                           | 4428                                                           |
| Tianjin      | NA                                | NA                                | NA                                | NA                                | NA                                                                  | NA                                                                 | NA                                                             | NA                                                             |
| Yunnan       | 2659                              | 7707                              | 5013                              | 8946                              | 2267                                                               | 2277                                                               | 4274                                                           | 2643                                                           |
| Zhejiang     | 3042                              | NA                                | 3069                              | NA                                | 4176                                                               | NA                                                                 | 4213                                                           | NA                                                             |

Notes: Delivery Type 1: Manufacturing companies deliver YYB to township hospitals; then, village doctors come to township hospitals to collect YYB monthly and caregivers get YYB from village health posts. Delivery Type 2: Manufacturing companies deliver YYB to township hospitals; then, caregivers come to township hospitals monthly to obtain YYB.
4. Discussion

We assessed the distributional consequences of the potential rollout of a YYB program on stunting prevalence in China. We found that the estimated cost-effectiveness would vary substantially by province, poverty status, delivery method and YYB coverage, from as low as ¥800 ($220) per stunting case averted (Chongqing) to as high as ¥23,000 ($6600, Jilin province). Chongqing, Jiangxi, Sichuan, Guangdong and Guangxi would generally present a lower cost to avert a stunting case (greater cost-effectiveness), while Anhui, Gansu and Jilin would present a higher cost (lower cost-effectiveness).

Moreover, in most provinces, the cost to avert a stunting case would be cheaper among children living in poverty, pointing to both the efficient and pro-poor potential of YYB rollout in China. Although the majority of the pilot YYB experiments recruited children only based on age (e.g., all children aged 6–36 months in selected counties) without taking household income into consideration [15–21], our results suggest that targeting the poor population might be potentially more cost-effective and equity-enhancing in China. However, we should note that many logistical issues would need to be considered when targeting the poor only, which might elevate the cost, such as identifying the poor and reaching out to them. Hence, for provinces where the poor are already identified and involved in other welfare programs, policymakers might consider only targeting the poor and adding YYB to the already existing welfare package.

We also found that the cost per stunting case averted would be lower in almost all provinces if YYBs were collected by village doctors from township hospitals and then caregivers would obtain them from village doctors, compared to caregivers coming to township hospitals to collect YYBs directly. Our study accounted for the costs borne by caregivers and found it more costly when caregivers traveled to township hospitals to obtain YYB (Delivery Type 2). Delivery Type 1 is the dominant delivery method in China [31]; however, Delivery Type 2 would lower government costs [44]. Therefore, policymakers should choose YYB coverage and delivery type based on both the government financial capacity and the willingness of caregivers to bear a share of the total cost.

Nevertheless, our analysis presents a number of limitations. First, there is uncertainty in several of our input parameters, including, for example transportation costs from manufacturing companies to township hospitals (TM). TM was based on the assumptions that it would increase linearly with lower road density: although similar modeling was applied previously [34–38], TM may not vary linearly with road density, but discontinuously as transport means used may change with road density (e.g., trucks could play a dominant role in places with higher road density) [45]. Although our sensitivity analyses allowed for variation in transportation costs, due to limited data, we still assumed similar TM costs for reaching all households within a province. Second, YYB coverage was assumed to be either 25% or 75%, and we neither sought an optimal coverage target (i.e., most cost-effective) for each province nor questioned the feasibility of our assumed coverage rates. Third, the economic evaluation we conducted is only one element toward priority setting, and decision-making is a complicated process. In addition to cost-effectiveness analysis or ECEA, decision-making processes should incorporate multiple considerations such as ethical, social and political factors. However, we assessed the likely equity impact of the YYB intervention, which is essential in a country with enormous heterogeneity such as China. Fourth, our study only considered rural China and thus ignored the country’s large urban–rural disparities. Moreover, we adopted the World Bank’s international poverty line of $5.50 per day, which could be revisited. For example, the GDP per capita in Jiangsu was around ¥95,000 ($26,000) in 2016, more than three times higher than in Gansu the same year (about ¥28,000 or $7000); hence, using the same poverty line across provinces may present some limitations. Fifth, although we considered adherence rates in our sensitivity analyses, we were uncertain how adherence would specifically affect effectiveness. For example, if children only took YYB for nine months (instead of 12), the adherence rate would be 75%, but the effectiveness might be maintained similar to the effectiveness of a 12-month intervention. Lastly, our study assumed that none of the children included in the CFPS survey were already covered by the YYB program, which might lead to an underestimation of the stunting cases that could be averted by YYB rollout, as well as an underestimation of the program effectiveness.
Despite the limitations, our study is novel in that it clearly stresses the distributional and equity implications of potential YYB rollout in China and points to the specific locations and provinces where YYB should be prioritized in terms of both efficient and equitable allocation. Our work highlights the pro-poor nature of YYB and how its rollout could redistribute population health in large and unequal low- and middle-income countries such as China. Future work should expand on our analysis by incorporating essential features capturing the feasibility and acceptability of different delivery scenarios. Furthermore, the effects of YYB can be multifaceted, including reducing anemia prevalence, strengthening anthropometric growth and improving cognitive development, which would add to the overall benefits of YYB beyond solely averting stunting. Future studies should be conducted to reveal the full broader impact of YYB.

Supplementary Materials: The following are available online at http://www.mdpi.com/2072-6643/12/9/2643/s1, Figure S1. Road density (km of road per 100 km² of land area) per Chinese province, 2015. Table S1. Cost type, symbol, definition and source. Table S2. Estimated transportation costs per pack, per province and poverty status (cents; RMB). Table S3. Estimated transportation costs per pack, per province and poverty status (cents; $. Table S4. Estimated total transportation costs per pack by delivery type, per province and poverty status (cents; RMB). Table S5. Estimated total transportation costs per pack by delivery type, per province and poverty status (cents; $). Table S6. Estimated total costs per pack by delivery type, per province and poverty status (cents; RMB). Table S7. Estimated total costs per pack by delivery type, per province and poverty status (cents; $). Table S8. Estimated total costs for a 12-month YYB rollout by province and poverty status (25% and 75% coverage, ¥ million). Table S9. Estimated total costs for a 12-month YYB rollout by province and poverty status (25% and 75% coverage, $ million). Table S10. Stunting prevalence by province and poverty status. Table S11. Estimated number of stunting cases by province and poverty status. Table S12. Cost-effectiveness of YYB program, by province and poverty status, when the effect size of YYB is halved (Cost ($) per stunting case averted). Table S13. Cost-effectiveness of YYB program, by province and poverty status, when the effect size of YYB is reduced to 0.96 cm (Cost ($) per stunting case averted). Table S14. Cost-effectiveness of YYB program, by province and poverty status, when the transportation costs (both for Delivery Type 1 and Delivery Type 2) are halved or doubled (Cost ($) per stunting case averted).

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Abbreviations

| Abbreviation                          | Definition                                      |
|---------------------------------------|-------------------------------------------------|
| China Family Panel Studies            | CFPS                                            |
| Confidence interval                   | CI                                              |
| Extended cost-effectiveness analysis  | ECEA                                            |
| Height-for-age Z score                | HAZ                                             |
| Standard deviation                    | SD                                              |
| World Health Organization             | WHO                                             |
| Ying Yang Bao                         | YYB                                             |

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