Article

Downshifting in the Fast Lane: A Post-Keynesian Model of a Consumer-Led Transition

Eric Kemp-Benedict [1,*] and Emily Ghosh [2]

[1] Stockholm Environment Institute; eric.kemp-benedict@sei-international.org
[2] Stockholm Environment Institute; emily.ghosh@sei-us.org
* Correspondence: eric.kemp-benedict@sei-international.org; Tel.: +1-617-590-5436

Abstract: If the world's countries seriously tackle the climate targets agreed in Paris, their citizens are likely to experience substantial changes in production, consumption and employment. We present a long-run post-Keynesian model for studying the potential implications of a major transition on macroeconomic stability and employment. It is a demand-led model in which firms have considerable but not absolute freedom to administer prices, while household consumption exhibits inertia. Firms continually seek input-saving technological improvements that, in the aggregate, tie technological progress to firms' cost structure. Together with firm pricing strategies and wage setting, the productivities of different inputs determine the functional income distribution. Saving and investment, and production and purchase of consumption goods, are undertaken by different economic actors, driven by income and capacity utilization, with the possibility that productive capacity exceeds, or falls short of, effective demand. The model produces business cycles and long waves driven by technological change. We present results for a "downshifting" scenario in which households voluntarily withdraw labor and discuss the implications of downshifting for stability, growth, and employment. We contrast the downshifting scenario with ones in which households reduce consumption without withdrawing from the labor pool.

1. Introduction

Shifting to a low-carbon economy is vital to limiting global temperature and curbing dangerous levels of climate change. World leaders committed themselves to climate action when over 195 countries (UNFCCC 2016) signed the historic Paris Agreement and pledged to take appropriate climate mitigation actions[1] to restrict global temperature increases to below 1.5°C (UNFCCC 2015). However, proposed country actions submitted as of November 2016 are insufficient to meet the temperature limit (Climate Action Tracker 2017). Ultimately, to prevent further warming, it will be essential to keep most of the remaining fossil fuels in the ground (McGlade and Ekins 2015; Benedikter et al. 2016). Because fossil fuel consumption has underpinned human development in the last two centuries, there is great reluctance to transition to different fuels.

---

[1]According to Article 4 paragraph 2 of the Paris Agreement, "…each Party shall prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions."

Given the urgency of the climate challenge, the question before us is, how can we accelerate a low-carbon transition? Recommendations tend to focus on technological choice and investment (UNEP 2011; OECD 2011; Green Growth Action Alliance 2013), yet there are reasons to think that major societal and lifestyle changes must accompany a low-carbon transition, as in all major technological transitions (Rhodes 2007; Bridge et al. 2013). If the transition is to be intentional, and rapid, it raises the question of the different roles of producers and consumers in initiating change.

In this paper we focus on middle- to high-income households in high-income countries in their roles as workers and consumers. Given global constraints on human activity – planetary boundaries (Rockström et al. 2009) – and a finite carbon budget (Messner et al. 2010), equity considerations imply a need for reduced physical throughput in high-income economies. The continued close association between GDP and material and energy flows (Ayres and Warr 2010) suggests we must make quality of life depend on more than GDP (E.g., Victor 2008; Jackson 2009), allowing GDP growth to slow and perhaps even fall for a time in high-income countries (Kallis, Kerschner, and Martinez-Alier 2012). Schor (2001) argues that reduced working hours in high-income countries, or "downshifting", is a strategy to address the "triple imperative" of reducing pressure on the environment, global poverty, and erosion of social capital in the course of economic development.

According to Schor (2001, 14), downshifting is "a quiet shift in values and behaviors away from consumerism. Downshifters either withdraw or partially withdraw from the labor force, mainly in order to achieve more balance, control and less stress in life". It is a strategy open to comparatively wealthy households and is motivated mainly by concerns over quality of life, rather than the environment. Nevertheless, it may have environmental benefits (Kennedy, Krahn, and Krogman 2013), particularly among the households with the largest environmental footprints.

Reducing working hours means less expenditure and less output. The same effect can be achieved by simply buying less, without reducing working hours. However, as we illustrate with the model described in this paper, the effects of the two strategies are quite different. Buying less without working less means higher savings, but also less incentive for companies to invest. This results in unemployment, but not immediately, and almost certainly not for the household that first curtailed its consumption. Reducing working hours, on the other hand, combines reduced employment with reduced expenditure within the same household.

Rezai et al. (2013) point out that downshifting may have perverse outcomes, because withdrawing labor will tighten the labor market, thereby driving up wages and inducing labor-saving technological change. They suggest that understanding the impact of downshifting requires analysis of the economy in the aggregate. In this paper we present scenarios of downshifting and reduced consumption using a model capable of addressing this question. It is being developed in order to better understand the dynamics of a transition to a low-carbon economy, and is in active development. In this paper we present the model in words; a mathematical presentation, now slightly out of date, can be found in a separate paper (Kemp-Benedict 2017c).

## 2. Methodology

We draw on several theoretical traditions, while remaining broadly within post-Keynesian economics (Lavoie 2014). We follow ecological economics in viewing economies as open systems embedded in societies, which are embedded in nature (Costanza et al. 2012). From evolutionary economics we draw the idea that economies are normally out of equilibrium (Schumpeter 1928; Nelson and Winter 1982), and from Blatt (1983) that the average state of the economy may differ substantially from the equilibrium. Following a long tradition in economics (Knight 1921; Keynes 1936; Shackle 1949), we view the future as fundamentally uncertain, a central concept in post-Keynesian economics (Davidson 1991; Dunn 2001). Because of uncertainty, economic actors' beliefs about the future significantly influence the trajectory of the economy (Beckert 2016). Theoretical and empirical work in post-Keynesian economics demonstrates the importance of demand, as well as supply, to long-run growth (Setterfield 2002). Moreover, demand and supply co-evolve (Witt 2001). With the Sraffians (Aspromourgos 2004), we agree that changes in the sectoral composition of production and consumption are relevant to long-term growth, and that the

89   distribution of income between profits and wages is influenced by wider social forces. Both the
90   evolutionary and post-Keynesian perspectives emphasize the historically contingent and
91   path-dependent nature of economic change.
92   We follow a general approach to macroeconomic modeling (cf. L. Taylor 2004), in which a set of
93   economic balances, or accounts, is supplemented by behaviors of economic actors. Once actors have
94   acted, the accounts are typically out of balance, so some parameter or combination of parameters
95   must adjust to clear the accounts. Once all of the accounts, behaviors and clearing mechanisms are
96   specified, the model is closed. Because models must be closed, fundamental uncertainty and
97   openness pose a challenge, but they are features of the real world, and they make a low-carbon
98   transition imaginable. We follow Setterfield (2003) by treating behaviors and clearing mechanisms as
99   conditional, dependent on both the research question and on historically contingent features of the
100   economy. This approach combines well with a scenario analysis (Bishop, Hines, and Collins 2007).
101   To be useful, a scenario model must be flexible enough to represent different narratives while
102   representing relevant systems sufficiently well to keep the scenarios within the wide but finite
103   bounds of what can realistically be posited about alternative futures (Bell 1997). In the
104   accounts-behaviors-clearing mechanisms approach to model-building, different scenarios can be
105   distinguished by different behavioral assumptions and pathways for exogenous variables. They may
106   also differ in the way the accounts are cleared. More rarely, the accounts themselves may change.
107   The essential components of the model documented in Kemp-Benedict (2017c) are shown in
108   Figure 1. It has five productive sectors: services, construction, manufacturing, agriculture, and
109   mining. It is a closed economy model with no government sector. The model is demand-led,
110   adjusting gradually through changes in capital and labor productivity, pricing decisions of firms,
111   wage-setting, and capital accumulation.
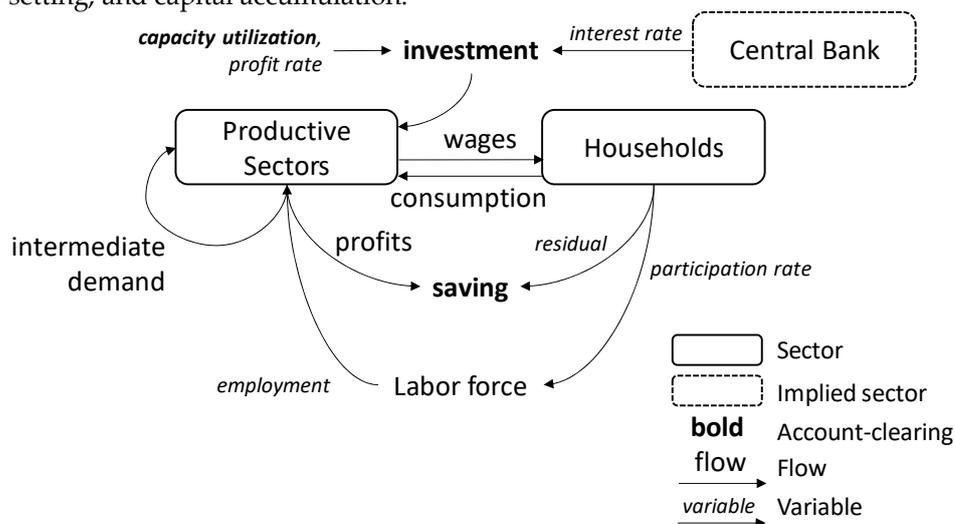
112

113   Figure 1: Main components, their interactions, and key variables

114   *Saving and investment*

115   In keeping with post-Keynesian theory (Lavoie 2014), separate decisions govern saving and
116   investment, so they are typically out of balance once actors have acted. The accounts are cleared by
117   adjusting capacity utilization. The model thus allows for underutilization of capital and
118   unemployment. We assume that all profits are saved, so although those profits may be retained by
119   firms or paid to households, in Figure 1 we show profits as a direct line from the productive sectors
120   to saving. Households may also save, or borrow, in an amount determined by the gap between their
121   wage income and their consumption.
122   Investment is determined by an investment function. When capital stocks are operating at
123   relatively high capacity, it is a signal to firms that more investment is needed; conversely, when
124   utilization is low it is a signal to slow down investment. Investment funds come implicitly from
125   retained profits, bank loans, or equity investment. Equity investors respond to returns. While the

126 model has no government sector, it implicitly includes a central bank, which sets an interest rate.
127 Higher interest rates mean higher borrowing costs, which discourage firms from taking on bank
128 loans. The investment rate (that is, new investment divided by the value of the capital stock) is
129 therefore an increasing function of both capacity utilization and the profit rate and a decreasing
130 function of the interest rate.

131 *Economic growth*

132 Growth in economic output is driven mainly by population growth and change in labor
133 productivity. Population in the model is calculated using a three-cohort demographic model, in
134 which the working-age population (cohort 2) has children (cohort 1), most of whom eventually grow
135 up to join the workforce, and eventually retire (cohort 3). The model also allows for immigration into
136 the working-age cohort and death in all three cohorts.
137 Labor productivity increases mainly through the use of labor-saving (and resource-using)
138 machines. Thus, labor productivity growth is driven largely (although not entirely) by capital
139 accumulation. The model combines cost-share induced technological change with a conventional
140 post-Keynesian assumption that labor productivity growth increases with the pace of capital
141 accumulation (the Kaldor-Verdoorn law) (Lavoie 2014, 428–30). In cost-share induced technological
142 change models, a rise in the cost share for one input to production (say, labor) stimulates faster
143 productivity growth in that input, while potentially slowing productivity growth in another input.
144 Such a model can explain the historically observed combination of rising labor productivity with
145 variable, but trendless, capital productivity (Kemp-Benedict 2017a).

146 *Stability, connection, and coordination*

147 Orders for investment goods increase capacity utilization and employment, so utilization
148 depends positively on investment. But as we earlier assumed that investment depends positively on
149 utilization, the model contains a positive feedback loop, which can be unstable. While
150 post-Keynesian theorists conventionally assume parameter values that guarantee stability, we
151 consider the evidence to favor instability (see Kemp-Benedict 2017c, 3–4); thus, our model is of the
152 Kaleckian-Harrodian type (Skott 2010). The instability is contained from above because capital
153 cannot be more than fully utilized. It is contained from below because the rate of disinvestment is
154 limited by the depreciation rate of capital. The result is a multiplier-accelerator model contained by a
155 ceiling and floor (Hicks 1950).
156 Counterintuitively, the unstable dynamics help to coordinate activity in different sectors. The
157 productive sectors are connected to one another through investment, the consumption expenditure
158 of their employees, and intermediate demand. Following post-Keynesian theory (Coutts and
159 Norman 2013), each sector sets its price as a mark-up on its costs; because expenditure on
160 intermediate goods is a cost, prices in different sectors are interrelated (Abraham-Frois and Berrebi
161 1997; Aspromourgos 2004; Kemp-Benedict 2017b). Nevertheless, these connections are not enough to
162 ensure that production plans in different sectors are coordinated. There is no guarantee that the
163 combination of household demand, demand for investment goods, and intermediate demand will
164 lead to balanced production (Pasinetti 1981).
165 The coordinating role of the utilization ceiling in the model can be illustrated with an analogy to
166 boats at a dock. When the tide is coming in, the boats are pushed against the dock. They line up, but
167 not because they coordinate their movements; rather, it is because the dock prevents them from
168 going further. When the tide goes out, each boat drifts away from the dock at a rate determined by
169 the currents and eddies where it is located. The boats are no longer neatly lined up, but the disarray
170 lasts only until the next time the tide comes in. The analogy is imperfect, because sectors are
171 connected, even if they are not coordinated. (To stretch the analogy, as a boat moved it would tend
172 to entrain the other boats.) In the model, the ceiling in the multiplier-accelerator model periodically
173 lines sectors up, like the boats at the dock. When the utilization ceiling is reached in one sector,
174 investment is high but consumption plans are frustrated, leading to under-consumption in other
175 sectors. The fall in consumer demand leads to a fall in utilization, which leads to a fall in investment

176   demand, which is only turned around because the fall in investment is halted by the floor of capital
177   depreciation. In the trough of the business cycle, some firms postpone investment, while others
178   continue to invest in expectation of a recovery. If that investment is sufficient, utilization eventually
179   returns close to normal levels. Investment increases with utilization, and the recovery turns into a
180   boom that continues until the utilization ceiling is reached once again.
181   Firms' expectations of future growth are informed by their experience of past growth, so as the
182   business cycle is repeated, investment and consumption patterns gradually align. When the
183   structure of the economy changes, those patterns are disturbed, but they eventually re-align over
184   time if expectations of future growth are sufficiently buoyant (Kaldor 1957, 601) to push utilization
185   rates to the ceiling. If they are not sufficiently buoyant, then the economy can go into a prolonged
186   slump, with utilization rates falling to different degrees in different sectors. In the analogy to boats at
187   a dock, this corresponds to the failure of the incoming tide. Without that coordinating force, the
188   boats drift ever farther from the dock.

189   *Wages*

190   For wage setting, we adopt the Goodwin (1967) model, which ties changes in the real wage to
191   labor productivity gains and unemployment. At normal levels of unemployment, wage rates rise at
192   the same rate as productivity. They rise more slowly than labor productivity when unemployment is
193   high and more quickly when unemployment is low. Unlike Goodwin, we express money wages in
194   nominal terms. Wage raises are applied to current rates, followed by a cost of living adjustment that
195   anticipates inflation. As it is difficult to negotiate a reduction in nominal wage rates, we apply the
196   cost of living adjustment only if inflation is positive.
197   Each sector has some flexible and some inflexible labor. Flexible labor is laid off and re-hired
198   over the course of a business cycle, while inflexible labor is maintained. Employed labor is drawn
199   from and released into the labor force; that is, the working-age population that is participating in the
200   labor market. The unemployment rate depends on the number of working-age people participating
201   in the labor force. We assume the participation rate follows the unemployment rate with a lag. When
202   unemployment is persistently high, job seekers become discouraged and exit the labor force. When
203   unemployment falls, more of the working-age population is drawn into the labor force, but with a
204   delay as they learn about changed conditions in the labor market, adjust routines at home, and
205   refresh skills.

206   *Prices and inflation*

207   Most prices in modern economies are administered (Means 1935, 1972). This observation
208   underpins post-Keynesian pricing theory (Lee 1999; Coutts and Norman 2013), in which most
209   sectors are dominated by a few large firms (oligopoly) that set their prices as a mark-up on costs to
210   generate profits. However, they do not have complete freedom, because excessive profits
211   encourages entry by rival firms. There is competition under oligopoly, but as price wars are
212   damaging to all firms, it is mainly carried out on such non-price dimensions as reputation, new
213   products or features, and customer relations.
214   In the model, total costs are equal to labor costs plus the cost of intermediate inputs purchased
215   from other sectors. Tracking intermediate costs through the network of inter-sectoral exchanges,
216   each sector's costs can be expressed in terms of wage costs across its supply chains (Pasinetti 1973).
217   Thus, wage costs ultimately determine prices. Inflation occurs when wages rise faster than labor
218   productivity[2]. This introduces a circularity in the model. The wage-setting procedure described
219   earlier occurs in two steps: first, the intended real wage increases faster or slower than labor
220   productivity depending on the unemployment rate; then a correction is added for anticipated

---

    [2] Firm costs include more than wages and costs of intermediates. Of particular importance for
sustainability studies, raw materials costs also enter into firm costs, and can also drive inflation. We
defer adding raw materials costs to a later version of the model.

221 inflation. But the reason inflation occurs in the first place is that wages rise faster than labor
222 productivity.
223   The ultimate source of inflation in the baseline scenario is the unstable investment dynamics.
224 During an expansion, there is increased demand for investment goods, and therefore labor in the
225 sectors that produce those goods. Those workers spend their incomes, generating demand for more
226 goods, feeding the expansion and driving inflation. Because inflation ultimately comes from
227 investment decisions, it can be moderated by influencing investment. This is accomplished in the
228 model by tying the interest rate (which enters the investment function) to the inflation rate through a
229 "Taylor rule" (after J. B. Taylor 1993).

230 *Consumption*

231   A substantial amount of household expenditure is routine: locked in through contracts or the
232 costs of operating durable commodities; constrained by the location of home, work and school; or
233 imposed by physiological necessity. In the 2014 US Consumer Expenditure Survey,[3] two-thirds of
234 all household expenditure was on housing, transportation, food, or apparel and related services. The
235 implication is that less than half of expenditure is flexible in the short run, helping to stabilize the
236 economy during the contraction phase of the business cycle. Over longer time scales, households
237 expand their consumption as their incomes rise. In the model we capture the combination of
238 long-run expansion and short-term inflexibility by assuming that a component of consumption
239 expands with total wages at normal utilization, while a further component varies over the business
240 cycle as realized wage income falls and rises.

241 *Active and inactive capital*

242   When the economy of a country or region fails, it is left with the shuttered buildings and
243 sometimes the machinery of the businesses that had once provided employment. Those buildings
244 and equipment are still accounted for as part of capital stocks through prior investment, but they are
245 not simply underutilized in the trough of the business cycle. They are inactive, and might not be
246 reactivated.
247   In the model, we account for inactive capital by moving some underutilized capital into an
248 "inactive" category. When investment picks up again, some of that investment is met by reactivating
249 inactive capital. In the baseline scenario, the fraction of inactive capital is negligible. It is more
250 relevant to scenarios in which economic output grows much less quickly, or shrinks.

251 **3. Results**

252   The model described above has multiple, interacting dynamics. Many of them are stable when
253 acting on their own, but operate with delays. Systems with these features typically show cyclical
254 behavior. Other dynamics, such as population or labor productivity growth, are always pushing
255 upward, while investment dynamics are locally unstable, but bounded by a ceiling and a floor. We
256 populated the model using a combination of values based on US data, typical values from the
257 literature, and values calibrated to give persistent business cycles in the baseline scenario.

258 *Structural change*

259   In the model, labor productivity growth differs between sectors, while expenditure shares per
260 unit wage and per unit of capital investment are held fixed. As a result, sectoral value added as a
261 share of GDP is nearly constant in the baseline scenario, while employment shares change
262 dramatically. When either labor productivity or expenditure shares (or both) change at different
263 rates in different sectors, full employment is not guaranteed (Pasinetti 1981, 87). In the model, a
264 long-run balance is maintained through interactions between employment, wages, prices, and
265 productivity growth.

---

[3] http://www.bls.gov/cex/

266   *Business cycles*

267   The model produces asymmetric business cycles, as observed in the US economy. As shown in
268   Figure 2, the business cycle in the model, as measured by utilization, falls rapidly (over 3 quarters)
269   and then rises slowly (over 19 quarters). This compares favorably to the post-World War II business
270   cycle average of 4 quarters of contraction and 19 quarters of expansion.[4] In the terminology of Sichel
271   (1993), the cycle in Figure 2 is both steep and deep. In fact, Sichel found evidence of steepness and
272   deepness only for unemployment in the US, and not for other macroeconomic indicators. In our
273   model, in its present form, capacity utilization, GDP and unemployment move together, so the
274   model must be extended if it is to explain different patterns in different variables.

275   A notable feature of Figure 2 is that no cycle is a precise copy of another, although they are
276   qualitatively similar. Partly this is because the model advances in discrete time steps (it is calculated
277   each quarter), but partly it is because the cycles result from multiple interacting processes, each with
278   its own characteristic time scale. The cycle for construction lags the cycles in other sectors, because
279   orders are placed for investment goods before they are actually built.[5] In keeping with the "boats at
280   the dock" analogy introduced in the methodology section, all sectors other than construction
281   converge on a similar utilization rate close to the peak, but fall to different degrees in the trough and
282   recover at different rates.

283
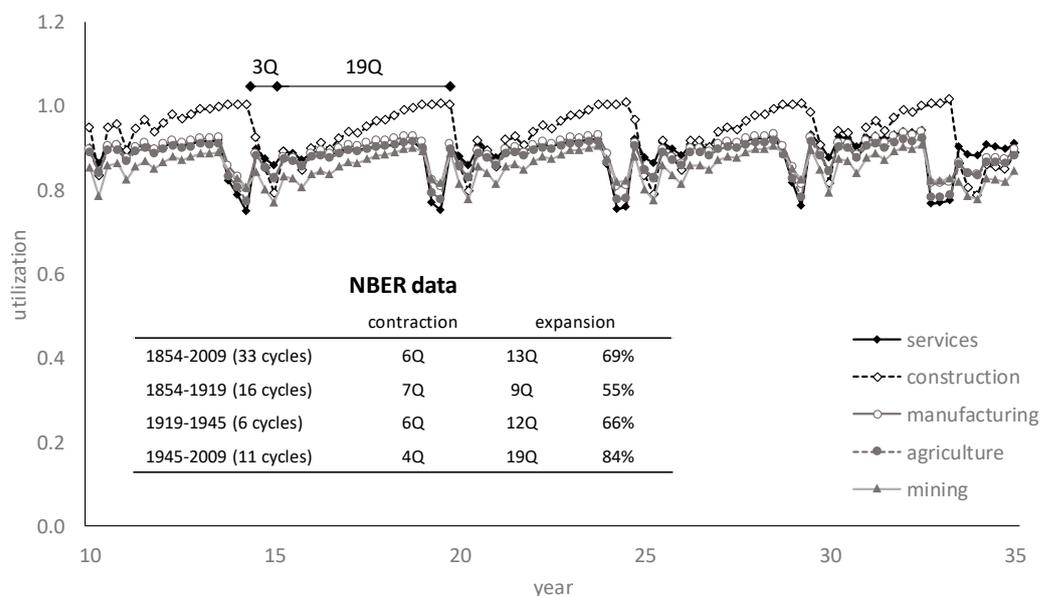
284

285   Figure 2: Business cycles in the baseline scenario, with data from the National Bureau of Economic
286   Research

287   *Long waves*

288   Underlying the business cycle are much longer cycles, of about 43 years. This is consistent with
289   the period of Kondratieff (1979) long waves, which are estimated to last between 35 and 60 years
290   (Metz 1992). The source of the waves in the model is the interaction between technological change,
291   pricing, and employment and wages. Rising employment and wages drive labor costs up. Because
292   prices respond after a delay, this shifts the distribution of income away from profits and towards
293   wages, stimulating labor productivity growth and dampening capital productivity growth. The

---

[4] As dated by the National Bureau of Economic Research (http://www.nber.org/cycles.html)

[5] Utilization in the construction sector slightly exceeds a value of one at the peak. This is allowed in the model because utilization is conventionally measured relative to maximum sustainable levels of production. It is possible to slightly exceed sustainable levels for short times.

294 combination reduces pressure on employment and wages, but also drives the profit rate down.
295 Firms respond by raising their mark-ups, driving the income distribution towards profits and away
296 from wages, encouraging faster capital productivity growth and slower labor productivity growth.
297 The cycle then repeats. Consistent with observation, capital productivity changes over time, but has
298 no clear trend, as the capital productivity growth rate cycles around a value of zero.

299 *Model behavior in alternative scenarios*

300   As discussed in the introduction, we contrast downshifting, or reducing working hours, with
301 reduction in consumption without reducing labor. In each scenario, we represent a transition as a
302 change in a model parameter that starts in year 100 (to allow some transient behavior to work itself
303 out) and continues for 25 years. We chose values that pushed the model close to a critical level, or
304 just beyond it, so they are much more substantial than actually observed consumer initiatives. In a
305 *downshifting* scenario we reduce the effective size of the working age population by 40% over the
306 time period, which leads temporarily to no GDP growth. In two *reduction* scenarios we reduce
307 consumption per unit wage by either 7.5% or 15% over the same time period. In the former scenario,
308 the economy continues, while in the latter it enters a deep slump.
309   In the following set of graphs we show the model behavior between years 75 and 150. The labor
310 force is shown in Figure 3. The effect of reduced working hours in the *downshifting* scenario is
311 evident in the figure. In the *7.5% reduction* scenario employment rises above the baseline after a
312 delay, while it falls off precipitously in the *15% reduction* scenario.
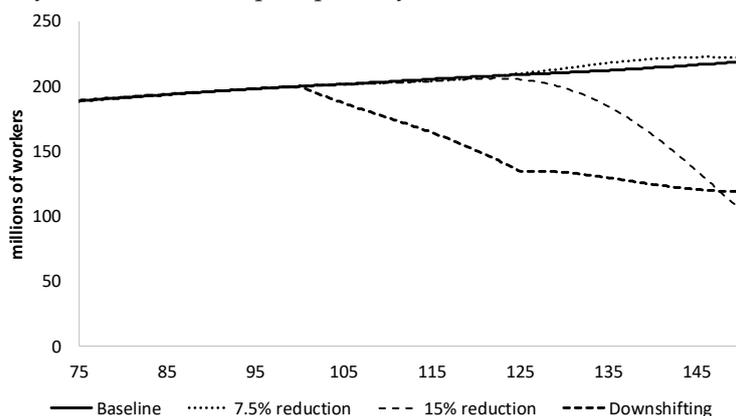
313

314   Figure 3: Labor force

315   The effect on consumption is shown in Figure 4. Relative to the *baseline* scenario, consumption
316 rises slightly in the *downshifting* scenario before it drops gradually to less than half the baseline level.
317 In the *15% reduction* scenario, consumption falls as the economic engine fails. In contrast, in the *7.5%*
318 *reduction* scenario, consumption not only recovers, it overshoots relative to the baseline.
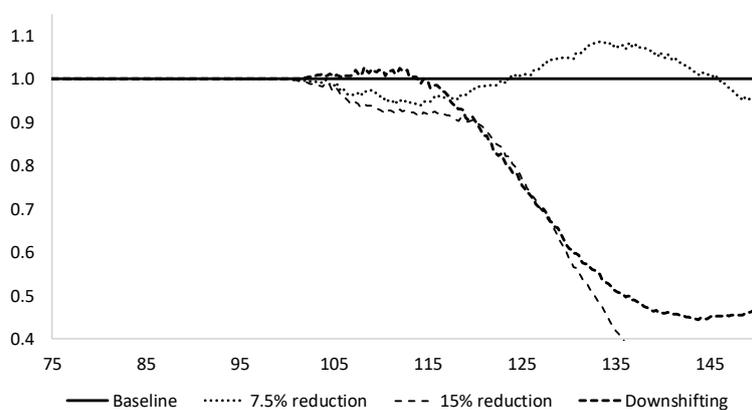
319

320   Figure 4: Real consumption relative to baseline

321   The trajectory of GDP in the scenarios is shown in Figure 5. As seen in the figure, GDP does not
322   grow in the *downshifting* scenario between year 115 and 135. After that it begins to pick up again. The
323   10-year lag between the reduction in work hours and the flattening of GDP is a result of multiple
324   interacting dynamics in the model. In the *7.5% reduction* scenario, GDP, like consumption, actually
325   rises above the baseline level for a time, while GDP collapses in the *15% reduction* scenario.
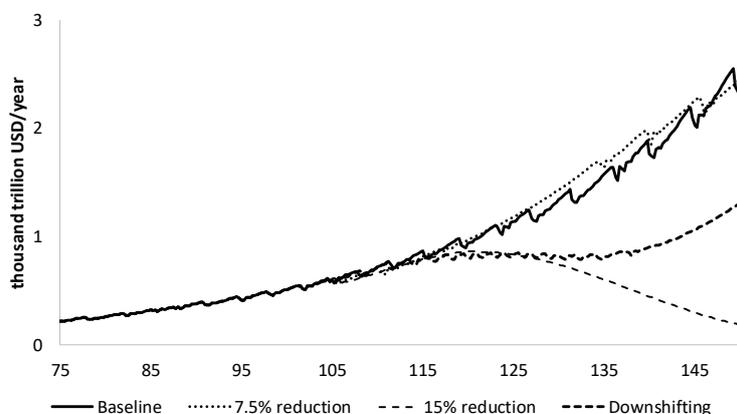

326

327   Figure 5: Real GDP

328   The *downshifting* scenario drives inflation, as seen in Figure 6. This effect, which was anticipated
329   by Rezai et al. (2013), happens because firms are unaware of the cultural phenomenon of
330   downshifting and are making their investment and production plans based on past experience.
331   Because less labor is available, it pushes wages up sharply. In contrast, when consumption is
332   reduced without withdrawing labor in the two *reduction* scenarios, inflation falls below baseline.
333   This deepens sharply in the *15% reduction* scenario and recovers and then overshoots in the *7.5%*
334   *reduction* scenario.
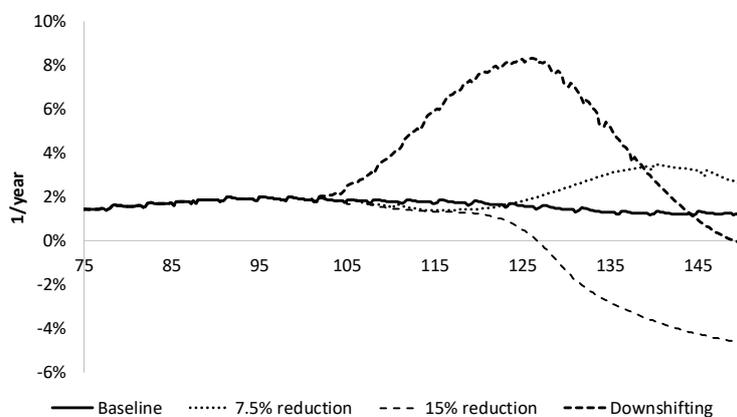
335

336   Figure 6: Consumer price inflation rate

337   Higher labor costs in the *downshifting* scenario stimulate investment in labor-saving technology,
338   again as anticipated by Rezai et al. (2013). The effect can be seen in the graph of manufacturing labor
339   productivity growth shown in Figure 7. The result is an increase in the capital-to-labor ratio, as
340   shown in Figure 8. That is, in the *downshifting* scenario, as employment and output fall, the economy
341   shifts towards labor-saving and more capital-intensive forms of production. The result is that the
342   capital stock continues to expand, even as GDP growth stagnates, albeit at a slower rate than
343   previously.
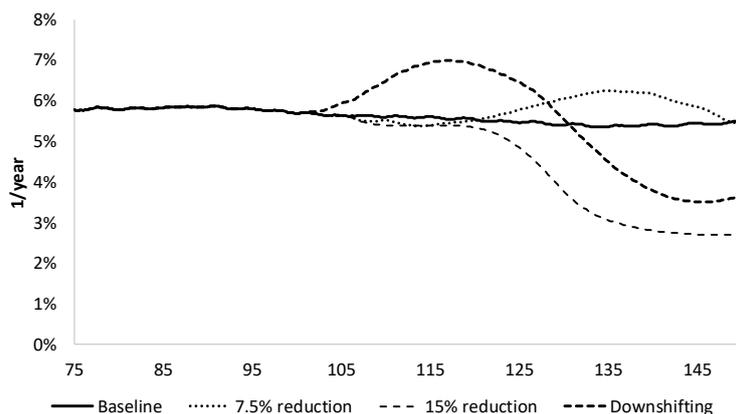
344

345   Figure 7: Labor productivity growth rate in manufacturing
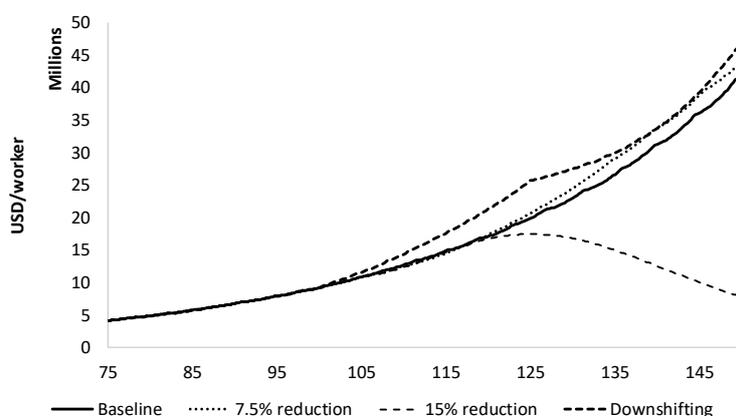
346

347   Figure 8: Capital to labor ratio

4. Discussion

349   In an economy out of equilibrium, the sequence of events matters. In an equilibrium model,
350 reduced consumption and reduced wage income happen together, whereas in a disequilibrium
351 model with delayed feedbacks it takes time for the system to accommodate the change, and actions
352 may not have their intended effects. In the model, reducing consumption without reducing working
353 time either has no net effect – the economy recovers and cycles around the baseline trajectory – or it
354 leads to a worsening contraction. In contrast, if workers reduce their working time, then the
355 economy can slow significantly without collapsing[6].

356   The model results shed some light on debates in ecological economics around the causes of
357 economic growth. Fractional reserve banking is not a driver of growth in this model (see Fontana
358 and Sawyer 2016 for a thorough discussion); our treatment of business investment is consistent with
359 a "horizontalist" position on money and banking (Lavoie 2011), in which the central bank is free to
360 set an interest rate, while commercial banks offer businesses the credit they demand. Furthermore,
361 without a financial sector, financialization is not driving unsustainable growth in the model (but is
362 likely to be important; see Jerneck 2017). Instead, growth is driven by the prospects for business
363 income. When those prospects are rosy, the economy tends to grow, and when they wither, the
364 economy can falter and even slide towards collapse.

365   The model has some limitations. A low-carbon transition must involve citizens, their
366 government, the private business sector, and trading partners, while the model presented in this
367 paper is of a closed economy without a government sector, and in the scenarios we presumed that

---

[6] A sufficiently large reduction in the labor force does lead to a self-reinforcing contraction in
the model, similar to that in the *15% reduction* scenario.

368 only households take the initiative. The model incorporates an assumption that expenditure varies
369 with wage income. That may be true as incomes rise, but households that are downshifting may try
370 to maintain their consumption by spending down savings, which would tend to sustain GDP.

371   These considerations aside, the results suggest that households can, at sufficiently large scale,
372 effect significant change in the absence of private sector or government action. The model takes an
373 aggregate view of the economy, as suggested by Rezai et al. (2013). The results support Schor's
374 (2005) contention that reducing work hours can be an effective strategy in reducing the footprint of
375 high-income households.

378 **Conflicts of Interest:** The authors declare no conflict of interest.

379
380 **References**

381 1.   Abraham-Frois, Gilbert, and Edmond Berrebi. 1997. *Prices, Profits and Rhythms of Accumulation.*
382   Cambridge ; New York: Cambridge University Press.
383 2.   Aspromourgos, Tony. 2004. "Sraffian Research Programmes and Unorthodox Economics." *Review of*
384   *Political Economy* 16 (2):179–206. https://doi.org/10.1080/0953825042000183181.
385 3.   Ayres, Robert U., and Benjamin Warr. 2010. *The Economic Growth Engine: How Energy and Work Drive*
386   *Material Prosperity*. Edward Elgar Publishing.
387 4.   Beckert, Jens. 2016. *Imagined Futures: Fictional Expectations and Capitalist Dynamics*. Cambridge, MA, US:
388   Harvard University Press.
389 5.   Bell, Wendell. 1997. *Foundations of Futures Studies: Human Science for a New Era*. New Brunswick, NJ, US:
390   Transaction Publishers.
391 6.   Benedikter, Roland, Kjell Kühne, Ariane Benedikter, and Giovanni Atzeni. 2016. "'Keep It in the Ground.'
392   The Paris Agreement and the Renewal of the Energy Economy: Toward an Alternative Future for
393   Globalized Resource Policy?" *Challenge* 59 (3):205–22. https://doi.org/10.1080/05775132.2016.1171665.
394 7.   Bishop, Peter, Andy Hines, and Terry Collins. 2007. "The Current State of Scenario Development: An
395   Overview of Techniques." *Foresight* 9:5–25.
396 8.   Blatt, John M. 1983. "Economic Policy and Endogenous Cycles." *Journal of Post Keynesian Economics* 5
397   (4):635–47. http://www.jstor.org/stable/4537777.
398 9.   Bridge, Gavin, Stefan Bouzarovski, Michael Bradshaw, and Nick Eyre. 2013. "Geographies of Energy
399   Transition: Space, Place and the Low-Carbon Economy." *Energy Policy* 53 (February):331–40.
400   https://doi.org/10.1016/j.enpol.2012.10.066.
401 10. Climate Action Tracker. 2017. "Effect of Current Pledges and Policies on Global Temperature." 2017.
402   http://climateactiontracker.org/global.html.
403 11. Costanza, Robert, Gar Alperovitz, Herman E. Daly, Joshua Farley, Carol Franco, Tim Jackson, Ida
404   Kubiszewski, Juliet Schor, and Peter Victor. 2012. "Building a Sustainable and Desirable
405   Economy-in-Society-in-Nature." New York, NY, US: United Nations Division for Sustainable
406   Development.
407 12. Coutts, Ken, and Neville Norman. 2013. "Post-Keynesian Approaches to Industrial Pricing." In *The Oxford*
408   *Handbook of Post-Keynesian Economics, Volume 1: Theory and Origins*, edited by G.C. Harcourt and Peter
409   Kriesler.
410 13. Davidson, Paul. 1991. "Is Probability Theory Relevant for Uncertainty? A Post Keynesian Perspective." *The*
411   *Journal of Economic Perspectives* 5 (1):129–43. http://www.jstor.org/stable/1942706.
412 14. Dunn, Stephen P. 2001. "Bounded Rationality Is Not Fundamental Uncertainty: A Post Keynesian
413   Perspective." *Journal of Post Keynesian Economics* 23 (4):567–87. http://www.jstor.org/stable/4538749.
414 15. Fontana, Giuseppe, and Malcolm Sawyer. 2016. "Full Reserve Banking: More 'Cranks' Than 'Brave
415   Heretics.'" *Cambridge Journal of Economics* 40 (5):1333–50. https://doi.org/10.1093/cje/bew016.
416 16. Goodwin, Richard M. 1967. "A Growth Cycle." In *Socialism, Cpaitalism, and Economic Growth: Essays*
417   *Presented to Maurice Dobb*, edited by C.H. Feinstein, 54–58. Cambridge,   UK: Cambridge University Press.
418 17. Green Growth Action Alliance. 2013. "The Green Investment Report: The Ways and Means to Unlock
419   Private Finance for Green Growth." Geneva, Switzerland: World Economic Forum.

420 18. Hicks, J. R. 1950. *A Contribution to the Theory of the Trade Cycle*. At The Clarendon Press ; Oxford.
421   http://krishikosh.egranth.ac.in/handle/1/2023601.

422 19. Jackson, Tim. 2009. *Prosperity without Growth: Economics for a Finite Planet*. Earthscan.

423 20. Jerneck, Max. 2017. "Financialization Impedes Climate Change Mitigation: Evidence from the Early
424   American Solar Industry." *Science Advances* 3 (3):e1601861. https://doi.org/10.1126/sciadv.1601861.

425 21. Kaldor, Nicholas. 1957. "A Model of Economic Growth." *The Economic Journal* 67 (268):591–624.
426   https://doi.org/10.2307/2227704.

427 22. Kallis, Giorgos, Christian Kerschner, and Joan Martinez-Alier. 2012. "The Economics of Degrowth."
428   *Ecological Economics* 84 (December):172–80. https://doi.org/10.1016/j.ecolecon.2012.08.017.

429 23. Kemp-Benedict, Eric. 2017a. "Biased Technological Change and Kaldor's Stylized Facts." Working Paper
430   76803. MPRA Paper. Munich, Germany: Munich Personal RePEc Archive.

431 24. ———. 2017b. "Dynamic Stability of Post-Keynesian Pricing." *The B.E. Journal of Theoretical Economics* 17
432   (2). https://doi.org/10.1515/bejte-2016-0013.

433 25. ———. 2017c. "A Multi-Sector Kaleckian-Harrodian Model for Long-Run Analysis." Working Paper 1702.
434   PKSG   Working   Papers.   Leeds,   UK: Post   Keynesian   Economics   Study   Group.
435   https://www.postkeynesian.net/working-papers/1702/.

436 26. Kennedy, Emily Huddart, Harvey Krahn, and Naomi T. Krogman. 2013. "Downshifting: An Exploration
437   of Motivations, Quality of Life, and Environmental Practices." *Sociological Forum* 28 (4):764–83.
438   http://www.jstor.org/stable/43653917.

439 27. Keynes, John Maynard. 1936. *The General Theory of Employment, Interest, and Money*. 2009 reprinting. New
440   York, N.Y.: Classic Books America.

441 28. Knight, Frank Hyneman. 1921. *Risk, Uncertainty and Profit*. New York: Harper & Row.

442 29. Kondratieff, N. D. 1979. "The Long Waves in Economic Life." *Review (Fernand Braudel Center)* 2 (4):519–62.
443   http://www.jstor.org/stable/40240816.

444 30. Lavoie, Marc. 2011. "Money, Credit and Central Banks in Post-Keynesian Economics." In *A Modern Guide*
445   *to Keynesian Macroeconomics and Economic Policies*, edited by Eckhard Hein and Engelbert Stockhammer,
446   34–60. Cheltenham: Edward Elgar.

447 31. ———. 2014. *Post-Keynesian Economics: New Foundations*. Cheltenham UK: Edward Elgar Publishing
448   Limited.

449 32. Lee, Frederic S. 1999. *Post Keynesian Price Theory*. Cambridge University Press.

450 33. McGlade, Christophe, and Paul Ekins. 2015. "The Geographical Distribution of Fossil Fuels Unused When
451   Limiting Global Warming to 2 °C." *Nature* 517 (7533):187–90. https://doi.org/10.1038/nature14016.

452 34. Means, Gardiner C. 1935. *Industrial Prices and Their Relative Inflexibility: Letter from the Secretary of*
453   *Agriculture, Transmitting in Response to Senate Resolution No. 17, a Report Relating to the Subject of Industrial*
454   *Prices and Their Relative Inflexibility*. U.S. Government Printing Office.

455 35. ———. 1972. "The Administered-Price Thesis Reconfirmed." *The American Economic Review* 62 (3):292–306.
456   http://www.jstor.org/stable/1803377.

457 36. Messner, Dirk, John Schellnhuber, Stefan Rahmstorf, and Daniel Klingenfeld. 2010. "The Budget
458   Approach: A Framework for a Global Transformation toward a Low-Carbon Economy." *Journal of*
459   *Renewable and Sustainable Energy* 2 (3):031003. https://doi.org/10.1063/1.3318695.

460 37. Metz, Rainer. 1992. "A Re-Examination of Long Waves in Aggregate Production Series." In *New Findings in*
461   *Long-Wave Research*, 80–119. Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-22450-0_4.

462 38. Nelson, Richard R., and Sidney G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge,
463   Mass.: Belknap Press of Harvard University Press.

464 39. OECD. 2011. "Towards Green Growth: A Summary for Policy Makers." Paris, France: Organisation for
465   Economic Co-operation and Development.

466 40. Pasinetti, Luigi L. 1973. "The Notion of Vertical Integration in Economic Analysis." *Metroeconomica* 25
467   (1):1–29.

468 41. ———. 1981. *Structural Change and Economic Growth: A Theoretical Essay on the Dynamics of the Wealth of*
469   *Nations*. Cambridge UK: Cambridge University Press.

470 42. Rezai, Armon, Lance Taylor, and Reinhard Mechler. 2013. "Ecological Macroeconomics: An Application to
471   Climate Change." *Ecological Economics* 85 (0):69–76. https://doi.org/10.1016/j.ecolecon.2012.10.008.

472   43.   Rhodes, Richard. 2007. "Energy Transitions: A Curious History." Stanford University: Center for
473   International   Security   and   Cooperation.
474   https://cisac.fsi.stanford.edu/sites/default/files/Rhodes-Energy_Transitions.pdf.
475   44.   Rockström, Johan, Will Steffen, Kevin Noone, Asa Persson, F. Stuart Chapin III, Eric F. Lambin, Timothy
476   M. Lenton, and et al. 2009. "Planetary Boundaries: Exploring the Safe Operating Space for Humanity."
477   *Ecology and Society* 14 (2). http://www.ecologyandsociety.org/vol14/iss2/art32/.
478   45.   Schor, Juliet B. 2001. "The Triple Imperative: Global Ecology, Poverty and Worktime Reduction." *Berkeley*
479   *Journal of Sociology* 45:2–16. http://www.jstor.org/stable/41035554.
480   46.   ———. 2005. "Sustainable Consumption and Worktime Reduction." *Journal of Industrial Ecology* 9
481   (1–2):37–50. https://doi.org/10.1162/1088198054084581.
482   47.   Schumpeter, Joseph. 1928. "The Instability of Capitalism." *The Economic Journal* 38 (151):361–86.
483   https://doi.org/10.2307/2224315.
484   48.   Setterfield, Mark, ed. 2002. *The Economics of Demand-Led Growth: Challenging the Supply-Side Vision of the*
485   *Long Run*. Cheltenham, UK ; Northampton, MA: Edward Elgar.
486   49.   ———. 2003. "Critical Realism and Formal Modelling: Incompatible Bedfellows?" In *Applied Economics and*
487   *the Critical Realist Critique*, edited by Paul Downward, 71–88. Routledge INEM Advances in Economic
488   Methodology. London, UK and New York, NY, US: Routledge.
489   50.   Shackle, G. L. S. 1949. "Probability and Uncertainty." *Metroeconomica* 1 (3):161–73.
490   https://doi.org/10.1111/j.1467-999X.1949.tb00040.x.
491   51.   Sichel, Daniel E. 1993. "Business Cycle Asymmetry: A Deeper Look." *Economic Inquiry* 31 (2):224–36.
492   https://doi.org/10.1111/j.1465-7295.1993.tb00879.x.
493   52.   Skott, Peter. 2010. "Growth, Instability and Cycles: Harrodian and Kaleckian Models of Accumulation and
494   Income Distribution." In *Handbook of Alternative Theories of Economic Growth*, edited by Mark Setterfield,
495   108–31. Edward Elgar Publishing.
496   53.   Taylor, John B. 1993. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on*
497   *Public Policy* 39 (December):195–214. https://doi.org/10.1016/0167-2231(93)90009-L.
498   54.   Taylor, Lance. 2004. *Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream*.
499   Cambridge, MA: Harvard University Press. http://site.ebrary.com/id/10328835.
500   55.   UNEP. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* Nairobi:
501   UN Environment Programme.
502   56.   UNFCCC. 2015. "Paris Agreement." http://unfccc.int/files/home/application/pdf/paris_agreement.pdf.
503   57.   ———. 2016. "Paris Agreement - Status of Ratification." 2016.
504   http://unfccc.int/paris_agreement/items/9444.php.
505   58.   Victor, Peter A. 2008. *Managing without Growth: Slower by Design, Not Disaster*. Advances in Ecological
506   Economics. Cheltenham, UK: Edward Elgar.
507   59.   Witt, Ulrich. 2001. *Escaping Satiation: The Demand Side of Economic Growth*. Berlin, Heidelberg: Springer
508   Berlin Heidelberg. http://dx.doi.org/10.1007/978-3-662-04528-2.